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TP 6300E

FINAL REPORT

THE CONCEPTUAL DESIGN OF AN ADVANCED CANADIAN HIGH CAPACITY HIGHWAY COACH

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BY

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UTDC RESEARCH & DEVELOPMENT LTD.

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DISCLAIMER

The contents of this report reflect the views of the contractor and not necessarily the official views of the Transportation Development Centre of Transport Canada.

PROJECT TEAM

UTDC Research and Development Ltd.	Prime Contractor
Moulton Developments Ltd.	Subcontractor-Suspension
Manitoba Industrial Technology Centre	Subcontractor-Structural Analysis
GSM Design Inc.	Subcontractor-Industrial Design
Chadwick Engineering	Subcontractor-Baseline Structure
Brian Clark Associates	Subcontractor-Operational Requirement

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17. Abstract

The project objective was to complete the conceptual design work required to manufacture a Canadian, advanced technology, double-deck intercity coach. The required subsystems were evaluated with lead and back-up candidates chosen. A number of possible vehicle configurations were evaluated, including front, mid and rear-engined designs.

The result of the above studies was the selection of a leading candidate design; a 12.2 m long double-deck coach with a rear engine driving the third axle. The structure is largely of stainless steel with more advanced light-weight materials used where justified. The vehicle has outstanding transportation efficiency in terms of empty weight per seat and is capable of up to 167 passenger kilometres/litre of diesel fuel. Estimated life cycle costs are at or below equivalent single-deck coaches and a low selling price of $320,000 is attained by utilizing proven techniques of construction where possible.

It is concluded that the selected vehicle is both economically and technically viable.

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17. Résumé

Cette recherche visait à compléter l'étude du schéma de base d'un autocar à impériale de conception avancée devant être fabriqué au Canada. Pour chacun des sous-systèmes du véhicule, on a procédé à une évaluation comparative des options en présence, laquell a permis le choix de deux options dont la première serait à privilégier. Plusieurs architectures ont été considérées: à motorisation avant, arrière ou médiane.
La recherche a débouché sur la sélection du schéma de base à privilégier, à savoir un autocar à impériale de 12,2 m de longueur, avec moteur monté à l'arrière entraînant le troisième essieu. La carrosserie est constituée largement d'acier inoxydable, mais des matériaux modernes plus légers sont retenus là où c'est possible. Le rapport poids à vide/nombre de sièges est excellent tandis que, du point de vue du rendement, on prévoit obtenir 167 passagers-kilomètres par litre de carburant diesel consommé. Le coût global sur la durée de vie est égal ou inférieur à celui d'un autocar simple comparable. Enfin, l'utilisation maximum de techniques de construction connues permet de proposer un prix de vente relativement bas de 320 000 $ l'unité.
Le rapport conclut en disant que le véhicule sélectionné est à la fois économiquement et techniquement intéressant.

18. Mots-clés	19. Diffusion
Autocar à impériale, autobus grande capacité, transport intervilles, transport de personnes	Le CDT dispose d'un nombre limité d'exemplaires.

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TABLE OF CONTENTS

Section		Page No.
	Title page	i
	Disclaimer	ii
	Project Team	iii
	Acknowledgement	iv
	Report Documentation Form (English)	v
	Report Documentation Form (French)	vi
	Table of Contents	vii
	List of Figures	ix
	List of Tables	ix
1.0	INTRODUCTION	1
1.1	Background	1
1.2	Conceptual Design Objectives	1
1.3	Project Methodology	1
1.4	Organization of the Report	2
2.0	THE OPERATIONAL REQUIREMENT	3
2.1	Performance Targets	3
2.2	Economic Targets	3
3.0	SUBSYSTEM EVALUATION	6
3.1	Power Train	6
3.2	Suspension and Steering	7
3.3	Brakes, Wheels and Tires	7
3.4	Heating, Ventilating and Air Conditioning	8
3.5	Auxiliary Drives	8
3.6	Summary of Subsystem Selections	9
4.0	CONCEPTUAL DESIGN	10
4.1	Layout Considerations	10
4.2	Flexible Configuration	10
4.3	Structural Considerations	10
4.4	Design Study	15
4.5	Optional Configurations	16
5.0	PERFORMANCE EVALUATION	18
5.1	Aerodynamic Assessment	18
5.2	Performance Summary	20
5.3	Risk Assessment	21
5.4	Life Cycle Costs	22

TABLE OF CONTENTS (CONT'D)

Section		Page No.
6.0	COMPARISON TO SINGLE DECK VEHICLES	25
6.1	Benefit Analysis	25
6.2	Performance Comparison	25
7.0	DEVELOPMENT AND MANUFACTURING	27
7.1	Preliminary Development Plan	27
7.2	Manufacturing Plan	27
7.3	Manufacturing Costs	29
8.0	CONCLUSIONS AND RECOMMENDATIONS	31
9.0	REFERENCES	
	APPENDIX - DESIGN PORTFOLIO	

LIST OF FIGURES

FIGURE		PAGE NO.
1.	Vehicle Cross-section	5
2.	Steel Tube Baseline Structure	13
3.	Location of Intake and Exhaust Cooling Flows, Rear Engine Bus	19
4.	Development Plan	28

LIST OF TABLES

TABLE		PAGE NO.
1.	Summary of High Capacity Intercity Coach Operational Requirements	4
2.	Power Train Options	6
3.	Comparison of Arrangement Options	11
4.	Weight Breakdown, Baseline Vehicle	12
5.	Summary of Conceptual Design Compared with Representative Single Deck Design	17
6.	Comparison Of Vehicle Transportation Efficiency	26

1.0 INTRODUCTION

1.1 BACKGROUND

The possibility of introducing double deck vehicles into the Canadian intercity coach operating industry has been studied in both practical and theoretical senses for the last six years, with the bulk of the work funded by Transport Canada's Transportation Development Centre. The work has encompassed studies of economics and the potential market (1, 2, 3), preliminary conceptual design work (4, 5) and brief but valuable demonstrations of imported double deck coaches (6, 7).

The general conclusions drawn from the previous work are that there is market for such vehicles, though initially small, and that operating restrictions in terms of regulations and road obstruction heights would not impede introduction of double deck intercity coaches.

The current work takes the process a step further with a far more detailed and in-depth conceptual design and quantitative analysis than previously carried out, with the objective of developing a design that would meet the economic needs of the marketplace.

1.2 CONCEPTUAL DESIGN OBJECTIVES

The overall objective is to reduce petroleum consumption and improve the productivity and operating efficiency of intercity bus transportation in Canada.

The specific project objective is to complete the conceptual design work required to manufacture a Canadian, advanced technology, double-deck coach.

1.3 PROJECT METHODOLOGY

The work initiated with a detailed work plan which defined both UTDC and subcontractor tasks. The operational requirements were developed based on a variety of sources, chiefly interviews with operators, review of the available literature, review of applicable regulations and the consulting assistance of an experienced operations manager formerly with a major coach line. These operational requirements were framed in great detail for a baseline vehicle, and more general targets for an advanced design were set that would enable economic viability for an operator (8).

Each of the subsystems required for the vehicle (e.g., power train) were separately studied, bearing in mind the overall requirements and design targets, and lead and back-up candidates selected in each area (9). These systems were then integrated into an overall vehicle design. In this conceptual design task different layouts, structural materials, and assembly techniques

were considered (10). During this latter process the subsystem evaluations were reconsidered and updated where required.

The performance of the resulting conceptual design was then evaluated from the view points of economic and technical viability in a series of tasks designed to assess the vehicle aerodynamics (11), performance (12), technical risk (13), and life cycle cost (14). The work concluded with forward planning of subsequent development phases and a final report.

1.4 ORGANIZATION OF THE REPORT

The report follows the outlined methodology with the operational requirements reviewed in Section 2.0, the subsystems discussed in Section 3.0, the conceptual design follows in Section 4.0 and the various performance evaluations reviewed in Section 5.0. The report then compares the resulting vehicle performance with existing vehicles (Section 6.0) and concludes with a development plan (Section 7.0) and conclusions and recommendations (Section 8.0).

Included as an Appendix is a portfolio of drawings and artist's renderings of the conceptual design.

2.0 THE OPERATIONAL REQUIREMENT

2.1 PERFORMANCE TARGETS

The design of the coach is intended to meet the "General Operating Requirements" detailed in Reference 8. These requirements were derived from a variety of sources, namely:

- Enquiries of operators;
- The UTDC R&D Data Bank;
- UMTA and DOT (USA) Standards;
- Applicable Canadian and USA regulations.

The methodology and results are discussed in detail in Reference 8. The resulting performance requirement is summarized in Table 1. Briefly summarized, the vehicle has to carry passengers, luggage and freight in a safe, comfortable and efficient manner on intercity highways. Variations on the basic designs are required to meet the charter and tour markets.

The principal departure from conventional North American practice is the maximization of the use of the existing regulatory envelope of:

- Height 4.115 m (13 ft. 6 in.);
- Width 2.59 m (8 ft. 6 in.);
- Length 12.2 m (40 ft.).

An increase in height over existing buses and careful suspension designs with self-levelling will enable operation with a ground clearance of 0.25 m. This affords the opportunity for two full decks allowing clearance for a 95th percentile adult male of height 1.88 m (6'2") (See Figure 1).

2.2 ECONOMIC TARGETS

The vehicle has to be economically viable for both the manufacturing and operating sectors of the intercity coach industry. For the manufacturing industry, this can be translated into the following terms:

- 20% return on investment after five years production;
- Initial sales - 50 per year.

For the operating industry the vehicle must be able to carry more people over the same routes for the same or lower vehicle-km costs. In order to achieve this it is necessary to reduce fuel consumption and maintenance costs in order to off-set the increased capital cost. The targets for the advanced double deck coach are:

- Fuel consumption decrease of 20%;
- Maintenance cost decrease of 15%;
- Maximum acceptable capital cost increase of 40%.

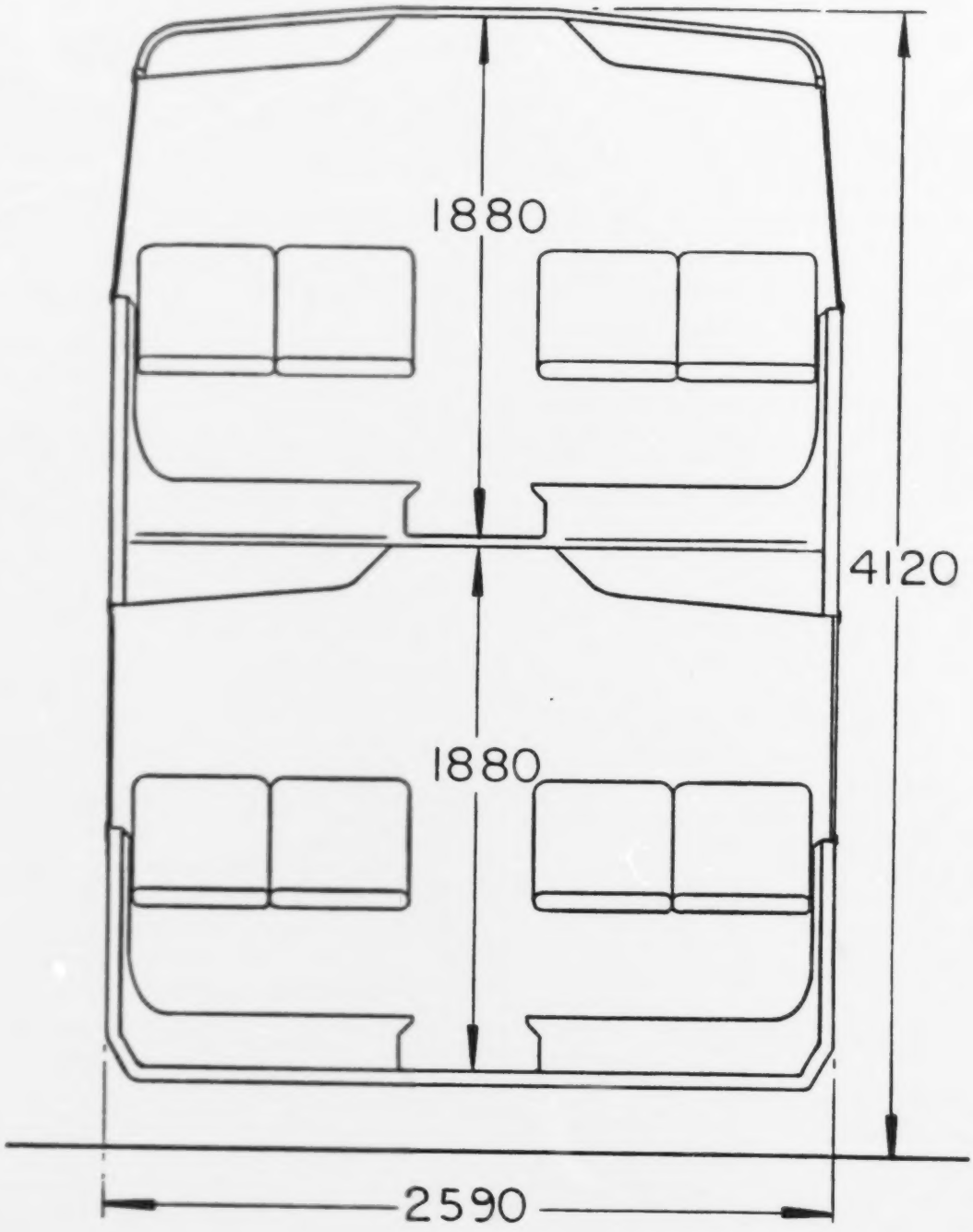
FEATURE	REQUIREMENTS
Speed	Cruise - 100 km/h Maximum - 110 km/h Grade at Cruise speed - 0.9%
Range	1000 km
Duty Cycle (Preliminary)	65% @ Cruise Speed and Cruise Power 20% @ Low power and Speed 10% @ Idle, 5% @ Full Power 3000 hrs. and 145,000 km per annum
Payload	80 to 100 passengers @ 75 kg each (1) Luggage for above @ 15 kg each Freight approx. 6.0 m^3 and 960 kg
Environmental	Altitude 0-2300 m Temperature -40 to +40°C (Normal Range) -51 to +46°C (Special Equipment) Relative Humidity 5 to 100%
Ancillary Services	Air Conditioning/Heating Compressed Air (Option hydraulics) 24 V DC (Option 110V, 60 Hz AC) Batteries
Noise	80 dBA Maximum Driveaway External 15 m 65 dBA Idle External 15 m 68 dBA Maximum Passenger Compartment
Reliability and Availability	145,000 km between Road Calls (2) 145,000 km minimum per year (2) 15-year Service Life (3) Availability 99.7% Scheduled Maintenance 10% of operating time
Safety	Equivalent to or better than Baseline Single Deck 12.2 m Coach

(1) Payload requirements vary (configuration should be flexible); e.g.,
commuter: maximum seating, minimum luggage;
intercity: conventional seating and luggage;
BPX: minimum seating, maximum luggage/freight.

(2) Average values over vehicle lifetime; new coach values should be 280,000 km.

(3) Service life is often 20 years in less arduous environments.

TABLE 1: SUMMARY OF HIGH CAPACITY INTERCITY COACH OPERATIONAL REQUIREMENTS



DIMENSIONS IN "mm"

FIGURE 1: VEHICLE CROSS-SECTION

3.0 SUBSYSTEM EVALUATION

3.1 POWER TRAIN

Currently available and longer term developments were considered in the selection process, and the use of alternative fuels reviewed. Selection criteria for the engine were power, weight, size, availability, cost, fuel efficiency, compatability with other subsystems and operational and maintenance characteristics. Engines considered included the diesel, advanced (e.g., adiabatic) diesels, gas turbines, fuel cells and the Stirling engine. This process is described in detail in Reference 9. The final engine lead and back-up candidates were all diesels based on the best combination of performance, cost, weight and availability. In the long term the adiabatic diesel with turbo-compounding or bottoming cycles is considered to be the best selection. These engines are to some extent compatible with alternate fuel, the lowest fuel cost option being a diesel converted to direct injection with spark ignition and natural gas fuel.

The selected power train consists of the DDA 6V-92 TA (250 kW @ 2100 RPM) coupled in a 'T' drive configuration to a 5-speed DDA HT-755 transmission with integral retarder and lock-up to reduce losses in the higher gears. This option offers the best trade-off between the power required to overcome aerodynamic drag, rolling and grade resistance, provide specified accelerations, and operate accessories while maintaining reasonable fuel consumption and compact packaging. Alternatives that would reduce fuel consumption at the expense of loss of commonality with existing equipment are outlined in Table 2.

Engine	Weight (kg)	Size (mm) l x w x h	Power kW	s.f.c.* kg/kW-h
- DDA 6V-92TA	916	965 x 965 x 1219	261	.201
- Gardner 6LYT	1043	1585 x 754 x 1283	239	.192
- Cummins L10	876	1308 x 805 x 1102	201	.195

Transmission	Weight (kg)	Size (mm) l x w x h	Gears	Power kW	Efficiency %
- Allison HT755	426	1041 x 572 x 650	5	320	-85 (lockup)
- Voith D864 G	375	1003 x 550 x 514	4	245	-85 (lockup)
- ZF HP 600	320	780 x 535 x 568	5	280	-85 (lockup)
- Kerr Train (estimated)	280	700 x 380 x 430	64	250	95

* s.f.c. = specific fuel consumption

TABLE 2: POWER TRAIN OPTIONS

The basic engine compartment layout can accommodate any of these variations and the more powerful DDA 8V-92 TA or Cummins 350 for increased performance in arduous environments.

3.2 SUSPENSION AND STEERING

The suspension and steering system were the subject of a detailed investigation reported in Reference 10, carried out by Moulton Developments Ltd. The study concentrates on an advanced air suspension and the hydro-pneumatic system as competing concepts offering good ride characteristics, all other options having been discarded at the subsystem evaluation phase (9). Design constraints imposed by the double deck configuration included the requirement for a lower deck aisle, 850 mm in width, at a low ground clearance of 250 mm, uninterrupted from the front door to the lower deck seats. Passage of a steering link under this aisle, and the high steering lock angles of up to 40 degrees necessary for a 12 m turning circle, demand careful packaging of the suspension and steering.

The hydro-pneumatic suspension is particularly suitable for the low floor requirement; good packaging is made possible by the unit's small size, ease of incorporating levelling, and elimination of shock absorbers which generally require regular replacement. Damping will be maintained for a long life by virtue of the large internal fluid volume and high surface area to reject heat.

Some advanced airbag suspensions are well proven on heavy vehicles, have low first cost and have shown to be competitive with the performance of existing conventional bus designs.

The main advantage for the hydro-pneumatic suspension is in performance for larger versions of the bus with two front axles, or the mid-engine concept with two front axles. This system is selected for integration into the vehicle because of its long term potential.

3.3 BRAKES, WHEELS AND TIRES

The components were extensively studied in Reference 9 and the selections discussed there were reviewed with operators. The major area of concern is the effectiveness of a parking brake on a hydraulic disc brake system when compared to an air actuated drum system. The finally selected braking system consists of:

- Front Axle(s)
  - Hydraulic Disc Brake
- Tag Axle
  - Hydraulic Disc Brake
- Drive Axle
  - Hydraulic Drum Brake
  - Parking Brake

The selected wheels reduce unsprung weight and offer a long service life. These are forged aluminum. The tire selection was based on performance and low rolling resistance. These are the Michelin Pilote.

3.4 HEATING, VENTILATING AND AIR CONDITIONING

This subsystem was also studied as part of the subsystem evaluation (9). Criteria used for the selection were weight, cost, reliability and maintainability, energy efficiency and noise. On these grounds a screw-type compressor operating on R-22 refrigerant was selected. The entire system including evaporator and condenser coils is located above the engine in its own sealed compartment, and driven hydraulically by the overall hydraulic accessory drive system.

To ensure passenger comfort, design requirements included:

- o interior temperature, 22°C to 25°C;
- o relative humidity, 40%;
- o ventilation rates:
  - 1.13 m^3/min/passenger forced air, 1.42 m^3/min/driver forced air, proportion of outside air variable from 20% at design point (heating or cooling) to 100% depending on outside air conditions;
- o apparent air velocity, less than 0.23 m/s;
- o capability of cool-down from 34°C to 24°C in a time of 15 to 30 min.

Capacity of the system for the 12.2 m bus is 10.0 tons cooling and 156,000 Btu/hr heating. This would increase to 12.0 tons cooling and 188,000 Btu/hr heating for the 15.2 m vehicle. Passengers are provided with 1.13 m^3/min of ventilation air and the driver 2.0 m^3/min. The quantity of outside air supplied in air-conditioning mode is 20% of the ventilation rate.

3.5 AUXILIARY DRIVES

The criteria by which the various auxiliary drives were judged were heavily weighted towards reliability and low maintenance requirements. Failure of even a small, low-cost component such as a drive belt can immobilize a vehicle as completely as an engine failure. Various reviews of the industry have shown that the large, high production volume items such as engines are, in fact, very reliable, and the accessories and their drives absorb a disproportionate maintenance effort. The major criteria for all auxiliary drives were:

- o reliability
- o cost
- o weight
- o size
- o maintenance and skill level required.

In addition, for drives of greater than 1 or 2 kW, the efficiency is of importance and, for all drives, the degree of control is of interest. The systems to be driven are alternator, air compressor, steering pump, coolant fan, air conditioning and potentially, hydraulic systems. The candidate systems are drive belt, direct drive, mechanical drive, electrical, hydraulic and an auxiliary engine.

To summarize the selection process carried out in Reference 9, drive belts were eliminated on the grounds of reliability and inefficiency. Electrical drives were both heavier and more expensive than the alternatives, and mechanical drives via shafts and gearbox are not sufficiently flexible for all versions of the coach that might be considered; thus these candidates were also rejected.

On grounds of compactness and reliability, the steering pump and alternator would be direct drives by gears mounted on the engine. The higher power, remote mounted, accessories such as the air conditioning compressor and cooling fan would be a hydraulic system based on the advantageous cost, weight and flexibility in both location and speed variation possible.

Consideration was given to an auxiliary engine to drive all auxiliary loads; the extra weight and cost of this unit compared to the incremental cost of the main engine to drive auxiliaries caused its rejection.

3.6 SUMMARY OF SUBSYSTEM SELECTIONS

The subsystem selections are summarized below. The main features of the preferred subsystems are:

- elimination of air system;
  - compressor
  - reservoirs
  - separators
- controllable A/C compressor and coolant fan RPM via hydraulic drive, therefore, power reduction;
- reduction in weight;
  - disc versus drum brakes
  - hydropneumatic suspension
  - air systems eliminated
  - independent front suspension
- improved control;
  - onboard communications
  - variable speed accessories
  - electronically controlled subsystems
  - disc brakes, hydraulically actuated.

4.0 CONCEPTUAL DESIGN

4.1 LAYOUT CONSIDERATIONS

Arrangements considered were front and rear wheel drive; front, mid and rear engine location, and varying proportions of lower deck seating. Vehicle lengths considered were the existing legal 12.2 m and stretched buses of 13.7 and 15.2 m (45 and 50 feet respectively). The 13.7 m vehicle was rapidly eliminated from further consideration for the following reasons:

- The extra length only provided one extra seat row downstairs and two upstairs, increasing capacity by 12;
- The extra weight demanded 4 axles versus 3 for the 12.2 m bus, increasing weight and complexity further;
- The resulting trade-off was not sufficiently favourable to justify further design effort.

The remaining options are compared in Table 3.

From these preliminary considerations it was concluded that for the previously defined operational requirement and market size envisaged, the leading and back-up candidates for further, more detailed work were:

- 12.2 m rear-engined, rear-wheel drive coach;
- 12.2 m mid-engined, rear-wheel drive coach.

4.2 FLEXIBLE CONFIGURATION

During the course of the work, and resulting out of contacts with industry operators and review of the program with the "Intercity Bus Ad-Hoc Advisory Committee" (15), it became apparent that there is a considerable range of potential operational modes which may for some operators be seasonal in nature. Thus, the remaining design work provided for reallocation of the lower deck space to provide within the same basic vehicle:

- All passenger commuter operation with minimum luggage;
- Luxury accommodation or charter arrangements;
- Conventional intercity passengers plus luggage;
- Provisions for the handicapped on the lower deck;
- All freight or increased luggage on the lower deck;
- Luggage loading through a rear door; although different from existing buses, this concept is acceptable to operators.

A number of these layouts are illustrated in the attached drawings and artists renderings.

4.3 STRUCTURAL CONSIDERATIONS

Structural materials considered included high strength low alloy (HSLA) steel, stainless steel, aluminum, composites such as

ARRANGEMENT	ADVANTAGES	DISADVANTAGES	CAPACITY	SUMMARY
12.2 m Front Engine Front-Wheel Drive	Stability.	Front tire loading. Lack of available components. Mechanical complexity. Poor access. Degree of acceptance.	74 passengers + 11.5 m^3 Luggage and freight	Eliminated from further consideration.
12.2 m Front Engine Rear-Wheel Drive	Stability. Use of spare next to driver.	Long driveshaft. Poor access. Degree of acceptance.	No further evaluation carried out	Eliminated from further consideration.
12.2 m Mid-Engine Pancake under Floor	Stability. Favourable configuration.	Engine access. Lower deck space. Utilization. Two sets of stairs.	61 passengers + 14 m^3 Luggage and freight	Eliminated from further consideration.
12.2 m Mid-Engine "Upright" Rear Wheel Drive	Simple engine access. Favourable configuration. Favourable structure. Low weight. Safety.	Engine noise. Depending on layout two sets of stairs might be required	69 passengers + 19 m^3 Luggage and freight	Retained for further consideration.
12.2 m Rear Engine Rear-Wheel Drive	Simple engine access. Low engine noise. Degree of acceptance. Simple layout.	Increased structural weight. Poor stability without careful detail design.	74 passengers + 10.1 m^3 to 53 passengers + 30.5 m^3	Retained as lead candidate.
15.2 m Rear Engine Rear-Wheel Drive	Simple engine access. Low engine noise. Degree of acceptance. Simple layout.	Increased structural weight. Medium stability.	98 passengers + 12.8 m^3 to 69 passengers + 37.1 m^3	Retained as lead candidate.

TABLE 3: COMPARISON OF ARRANGEMENT OPTIONS

fiberglass, kevlar and carbon reinforced plastics, and sandwich panels of various types. The structural elements for which they were considered include longitudinal members, frames, skin, floors, roof, and end caps.

Reducing structural weight was an objective of the program in order to reduce fuel consumption and wear and tear on vehicle components. This must be achieved while reducing maintenance cost, therefore corrosion resistance, fatigue resistance and ease of repair are also important criteria. In life cycle cost terms the Net Present Value of a 1% change in gross vehicle weight is represented by approximately $1,000 to $1,500 for a 15 year life when considering fuel consumption alone. Clearly if the material or constructional technique needed to achieve a reduction of 1% in GVW (approximately 200 kg) costs more than $1,000 to $1,500 to implement, it should not be considered. Weight reductions of 1% of GVW are more difficult to achieve than would appear at first sight, since the vehicle structure is only 30% of the total as indicated in Table 4.

Engine module, including transmission	2,144
Battery Pack	120
Fuel tank, filled	502
Air conditioning module	348
Rear drive axle assembly	1,236
Tag axle assembly	528
Steering axle assembly	745
Vehicle structure	6,074
Interior accessories, windows, doors	1,948
Floors, mats, rust proofing panels	773
Body molding, driver spare tire	422
Payload, 68 passengers, luggage, freight	6,580
	21,420 kg

C. of G.: x = .974 m to rear of coach center
y = .016 m to right of coach centerline
z = 1.812 m above ground

TABLE 4: WEIGHT BREAKDOWN, BASELINE VEHICLE

The materials were each evaluated in a generic sense for a "typical" application on the vehicle, such as roof or floor. It is apparent that no single material has all the virtues required for the whole vehicle structure. It was concluded from the survey that, primarily on cost and ease of manufacture grounds, the majority of the structure should be relatively conventional metallic materials, and that advanced composites should be used only where they confer an overwhelming advantage for the vehicle as a whole.

The baseline structure is shown in Figure 2 and is constructed of completely conventional steel tubing with steel skins welded to the tubing. Other techniques such as diagonal bracing and riveted skins were examined and rejected in favor of the monocoque structure which provides a clean surface and shorter assembly time. Flooring is conventional aluminum faced plywood, as used in

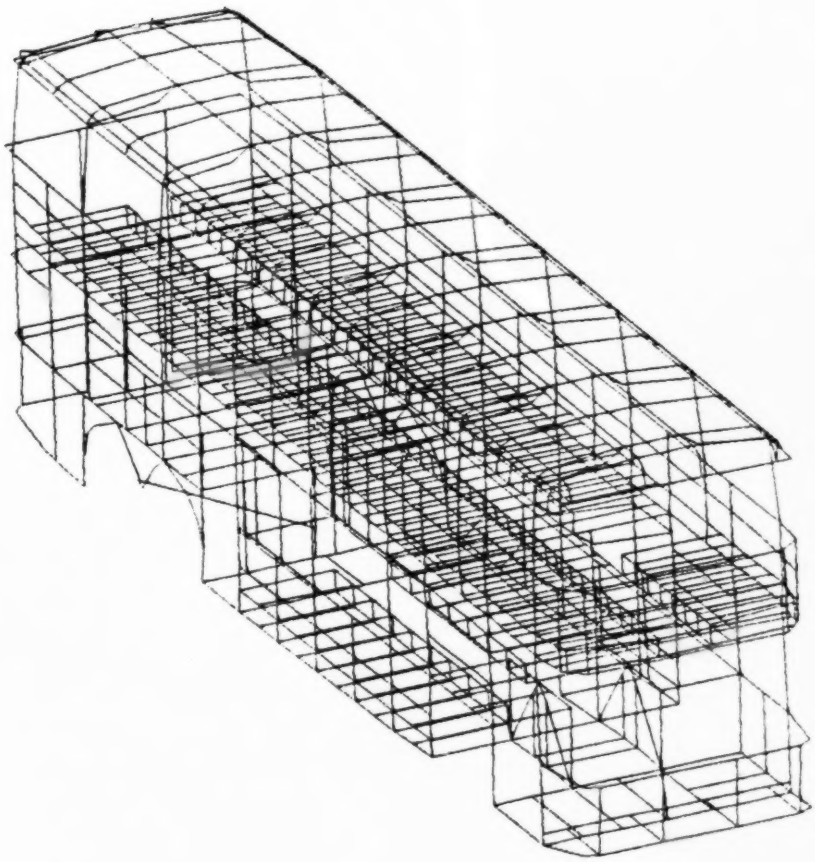


FIGURE 2: STEEL TUBE BASELINE STRUCTURE

many current bus designs. Entirely off-the-shelf sections were used for the frame, and conventional skin thickness assumed. In order to provide a firm basis for the overall design process, this structure was subjected to a rigorous finite element analysis by the Manitoba Industrial Technology Centre (MITC) (10).

The interaction between the structure and the suspension is clearly a critical one, and criteria were developed by the suspension consultants, Moulton Development, for the required vehicle structural stiffness and typical imposed loads (10).

The resulting structure at 6,074 kg is clearly heavy, and to this must be added 340 kg for the plywood flooring. This results in a baseline vehicle weight of some 21,420 kg, which is only just acceptable from tire and axle loading viewpoints and is unacceptable in some jurisdictions from a pavement loading viewpoint. In addition, some areas of the structure are overstressed and the floor of the upper deck is probably insufficiently stiff, while being at the same time of excessive weight. This is a result of the requirement to reduce structural depth to a minimum in this area. Minor redesign would eliminate these problems for the overall structure, and some elements are actually over-designed in this first iteration.

It is a firm conclusion that no large weight reduction is possible while retaining this structure in its' entirety. Therefore, trade-off studies were carried out for some critical elements of the vehicle.

4.3.1 Roof

Stresses in the roof are relatively low and this component is high off the ground leading to the added incentive to lower vertical c of g by reducing weight. It was concluded that the roof could be made in one piece, in a fiberglass composite,with both inner and outer skins pre-finished with an internal layer of insulation. The weight would be reduced from 543 kg to approximately 240 kg, and the cost and labour intensive task of insulating the roof and then fitting interior trim would be eliminated.

This part could also be made of aluminum honeycomb for most of the vehicle length, where single curvature only is required. This would still leave the insulation and trim task. The single piece FRP roof is preferred.

4.3.2 Upper Deck Floor

This floor is subjected to high vertical loads from the passengers, but also considerable shear resistance is required to prevent the vehicle from being insufficiently stiff in torsion to meet the suspension criteria. A number of materials were considered including aluminum honeycomb, advanced components, sandwich panel with balsa core, etc. This floor may be made in simple flat pieces and thus lends itself to aluminum honeycomb or FRP faced Nomex honeycomb core panels. On cost and ease of

attachment grounds, the aluminum honeycomb is selected resulting in a weight decrease from 1,084 kg to 550 kg, and vastly improved performance in terms of stiffness and a reduced number of pieces to assemble.

4.3.3 End Caps

The end caps of the vehicle are complex in shape and difficult to execute in traditional materials. Loads are relatively low and thus, FRP moldings are recommended with stiffeners built in to accept point loads. Weight reduction from 522 kg to 250 kg is possible, and aerodynamic contours could be improved as discussed in Section 5.1.

4.3.4 Summary of Structural Studies

In summary, the trade-off studies indicate a total structural weight reduction (including floors) of 1110 kg (from 6414 kg to 5304 kg) from the baseline design is readily achieved while improving structural stiffness, and without degradation of reliability, maintainability, corrosion resistance, and structural cost.

This 5½% reduction in weight enables a reduction of power requirement sufficient to enable use of smaller, generally 6 cylinder engines rather than the DDA 8V-92 TA, resulting in a further weight reduction of 180 kg for engine alone, and smaller reductions in engine fuel system, fuel, and cooling system, supports and mountings etc.

The net results of these changes is a total reduction of 1510 kg from the baseline design weight of 21,420 kg to a new Gross Vehicle Weight in the order of 19,910 kg.

4.4 DESIGN STUDY

The overall aesthetic design of the vehicle exterior and interior, and studies of access for the handicapped were carried out by GSM Ltd. and reported in detail in Reference 10. Essentially the requirements for the exterior were a clean looking exterior with low maintenance and low aerodynamic drag in mind, and a pleasing modern interior with design features now taken for granted in modern aircraft and intercity rail vehicles. The success of the approach can be judged from the figures appended in the Appendix 1. Principal features of the standard layout are:

- Stairs behind driver ascending over front wheel-well;
- Washroom on drivers side behind front wheel-well;
- Access for varying numbers of handicapped passenger on lower deck;
- Reclining seats for all passengers;

- Enclosed carry-on luggage bin for each seat;
- Flush mounted windows.

The standard layout has 53 upper-deck passengers and 15 lower-deck passengers at a comfortable seat pitch of 800 mm. Commuter variants of the vehicle with no washroom, reduced luggage space and a seat pitch of 725 mm would accommodate 82 passengers for shorter duration journeys.

It is conventional in vehicles of this type for the manufacturer to be relatively responsive to customer demand in terms of specific equipment, particularly in terms of the interior appointments. The basic vehicle is summarized in Table 5. The vehicle as described meets all of the Operational Requirements defined in Reference 8 with the exception of fuel consumption when calculated under the assumptions defined in the performance assessment (3) of 75% of full accessory load. This is a somewhat restrictive assumption when taken on an annual average basis, and fuel consumption improves to the values quoted in Table 5 for a more typical 50% accessory load. Use of a modern 4-stroke diesel, such as the Gardner 6LYT or Cummins L10, further improves the average duty cycle fuel consumption to 32.7 l/100 km at 2/3 load and 34.7 l/100 km at full load, compared to values of 34.8 l/100 km at 2/3 load and 37.0 l/100 km at full load for the vehicle fitted with a DDA 6V-92 TA.

4.5 OPTIONAL CONFIGURATIONS

The major option available is to develop a mid-engine bus with improved weight distribution, stability and fuel consumption based on a reduced structure weight at the expense of some loss of payload, increased development risk and difficulty of access within current maintenance facilities. Alternatively a 15.2 vehicle with four axles can be developed for either configuration. The following was concluded from the work carried out:

- Increased length versions of either rear or mid-engine layouts are not only technically feasible but offer advantages in terms of payload/empty weight efficiency.
- The mid-engined vehicle is technically superior and will have a fuel consumption some 3% better at full load increasing to 5% better at 2/3 load. The vehicle center of gravity will be closer to the aerodynamic center of pressure, resulting in better handling. A further advantage is the extra set of front wheels and brakes affording a safer system in the event of a tire blowout or brake malfunction. Experience in Europe has also shown that the first pair of tires clears the road of snow or rain for the second pair of tires, thus improving stability in poor weather.

SYSTEM	CONCEPT DESIGN DESCRIPTION	MC-9 CRUSADER II
Overall Dimensions	Length 12.2 m; Height 4.115 m; Width 2.59 m Front overhang 2.51 m: Steering to tag axle 6.10 m. Rear overhang 2.39 m: Tag to driven axle 1.20 m.	Length 12.2 m: Height 3.38 m; Width 2.44 m.
Weights	Curb 13,330 kg; Fully loaded 19,910 kg.	Dry Weight 12,200 kg Loaded 17,400 kg
Capacity	68 passengers @ 800 mm seat pitch; 10 kg carry-on luggage per passenger and 8 m^3 luggage/ freight	43 passengers, 860 mm seat pitch: luggage 8.5 m^3; 53 passengers, 780 mm seat pitch
Range	1300 km @ full load and average duty cycle	1150-1430 km
Fuel Consumption (1/100 km)	29.4 @ 2/3 load; 31.7 @ full load - cruise conditions; 50% accessory load. 34.8 @ 2/3 load; 37 @ full load - average duty cycle; 50% accessory load.	45 average
Arrangement	3 axle, rear engine drive to 3rd axle	3 axle, rear engine drive to 2nd axle
Structure	Major Structure: Stainless Steel skin weld/ bonded to stainless steel frame tubes with bonded stiffeners Roof and End Caps: FRP Composite Upper Deck Floor: Aluminium Honeycomb	Stainless steel lower frame, aluminum center roof & upper sidewall panels, molded fiber-glass front roof cap & rear roof crown.
Suspension	Front: Independent Hydro Pneumatic Tag: Independent Hydro Pneumatic Drive: Beam Axle, A-Frame, Hydro Pneumatic	Front & Drive: Air beam Tag: Independent pivot, air
Drive Axle	Rockwell 160	
Wheels & Tires	Tires: Michelin Pilote Wheels: Alcoa Forged Aluminum	Tires: Michelin 12R 22.5 XZA
Brakes	Front & Tag: Hydraulic Disc Drive: Hydraulic Drum and Parking Brake	Air, drum
Power Train	Engine: Detroit Diesel Allison 6V92TA Transmission: Allison HT755 5-speed with Integral Retarder	Engine: DDA 8V-71 Transmission: Fuller 5-speed, DDA HT740 4-speed
Interior	68 Reclining Passenger Seats, Drivers seat adjustable position. Closeable overhead luggage racks.	43-48 reclining seats, open overhead luggage racks
Options	Galley; Washroom; Wheelchair Tie Downs and Ramp All-Freight Lower Deck; Tour Guide Seat.	Washroom;

TABLE 5: SUMMARY OF CONCEPTUAL DESIGN COMPARED WITH REPRESENTATIVE SINGLE DECK DESIGN

5.0 PERFORMANCE EVALUATION

5.1 AERODYNAMIC ASSESSMENT

The configuration was developed based on available literature and was reviewed in a meeting with K.R. Cooper of NRC who has carried out extensive and relevant work in commercial vehicle aerodynamics at the NRC low speed wind tunnel laboratory in Ottawa.(11) Of direct relevance to the current design is the work forming the basis of Reference 16, which was published at the Annual SAE congress in February 1985. This investigation had studied simple leading and trailing edge treatments to reduce drag of commercial vehicles and the effects of Reynold's Number and yaw angle were studied.

The front edge radius used initially on the sides of the vehicle was acceptable in the zero yaw case but likely to be sensitive to both vehicle speed and yaw effects beyond 5° angle of attack. An increased angle of attack beyond this value would result in flow separation on the downwind side and increased drag. An improved shape would consist of a simple radius increased from 0.125 m to 0.2 m before the flat panel at 10° to the flow or a more elliptical profile executed in a composite end-cap that would allow compound curvature. The radius at top and bottom of the vehicle is not sensitive to wind angle and is 0.125 m.

The rear end of the bus can be improved by use of tapering. A shorter taper region at a greater angle of 15° instead of the 3° used initially would have equal or better drag reduction, and increase width in the region of the rear seat. In the revised design the rear end radii of 0.125 m would be eliminated or reduced,and could be dependent on styling considerations.

In order to reduce drag to a minimum the sides, roof and windows should be free of steps, gaps and transverse ribs (e.g., window frames). Thus the vehicle should have a smooth skin and flush mounted windows. The vehicle underbody is less critical but a general rule is to keep the various obstructions (such as axles, frames, equipment) in a horizontal line with no downward protrusions below a certain level.

The exact shape of wheel openings and mud guards should be the subject of wind tunnel development, however as a design guideline the wheels should be as flush as possible with the vehicle sides and with wheel disc covers. Complete fairings over the openings are seldom worth the extra cost and problems with brake and tire cooling, and are therefore not used in the design.

There are essentially two alternatives to providing the air-flows required for the cooling system and HVAC system:

- Front mounted ram intakes with fan assist in traffic and vehicle stationary modes;

- o Rear or side mounted intakes with continuously driven variable speed fan-drive.

For the rear engine location the length of cooling system piping and increased pumping losses partially reduce the advantages afforded by reduction in cooling fan power, in addition the unknown effects on front end aerodynamics of a large radiator must be measured in a wind tunnel. Similarly at the rear of the vehicle the exact placement and area of intake and exhaust grilles is critical. The suggested layout for the rear engined vehicle has an intake mounted on the vehicle side above the turbulent wake of the rear wheels and an exhaust across the rear of the bus (Fig. 3).

The mid-engine vehicle is more likely to benefit from a front radiator placement. The detail engineering phase of the program should include wind tunnel testing of the alternatives to enable the trade-off of installed fan power, pump power and propulsion power to be carried out.

One effect of achieving lower drag through the measures described in previous sections is the increasing proportion attributable to external protuberances such as the large rearview mirrors common on buses. Drag increases of 24% due to this one element are possible. The exact placement and fairing of the mirrors is made critical by their being immersed in the high velocity (higher than road speed) flow region in the vicinity of the leading edge radii. This is the second area where detail wind tunnel development work is required.

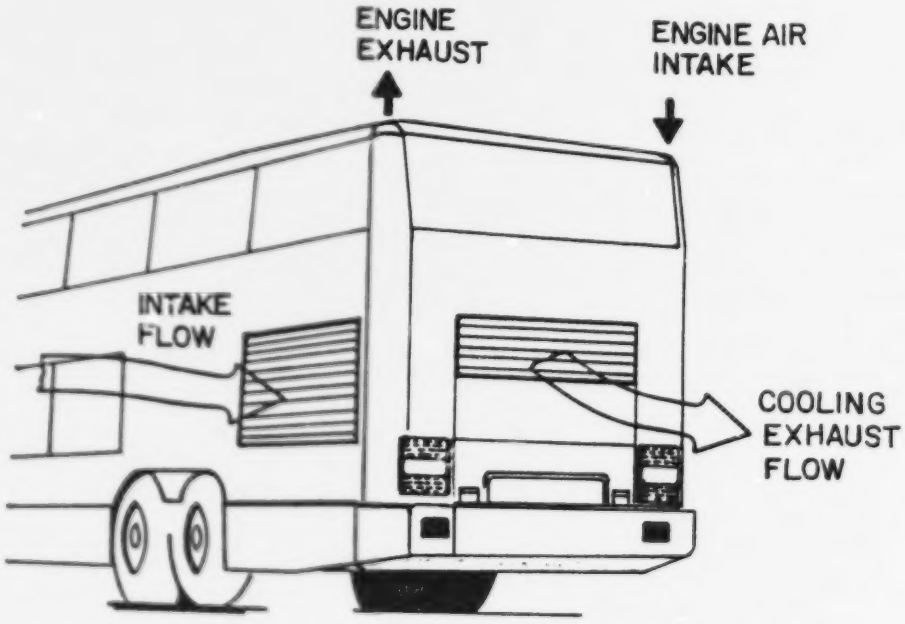


FIGURE 3: LOCATION OF INTAKE AND EXHAUST COOLING FLOWS, REAR ENGINE BUS

For design purposes the leading parameters of relevance to aerodynamic design derived from the assessment carried out are summarized below:

V_c = Cruise Speed: 100 km/h (27.78 m/sec)

A_f = Frontal Area: 10.15 m^2

L_R = Reference Dimension: $\sqrt{10.15}$ = 3.186 m

β max = Maximum Design Wind Angle: = 10°

R_e = Design Reynolds Number = 6.76 X 10^6

r_{FS} = Leading Edge Radius (Sides) = 0.2 m

r_{FT} = Leading Edge Radius (Top) = 0.125 m

C_{dw} = Wind Averaged Drag Coefficient = 0.4 (Could be reduced to 0.35 by detail wind tunnel work)

Cp = Centre of Pressure = 0.9 m ahead of Vehicle Mid Point (43% of length behind nose)

5.2 PERFORMANCE SUMMARY

Coach performance and power estimates were determined, under a variety of vehicle load conditions and engine selections(power and specific fuel consumptions) as well as driveline efficiencies (Allison 5-speed vs high efficiency Ker-Train). Predictions for the baseline vehicle before technology improvements were made, indicated that the engine best meeting the power requirements for speed and acceleration under all load conditions and accessories operating would be the DDA 8V92TA, 298 kW (400 HP) version. However, for the average duty cycle defined in Table 1, the initial baseline vehicle configuration did not meet the operational requirements in terms of overall fuel consumption.

As a result, several technology improvements were examined to enable the advanced high capacity coach, the objective of this study, to fully meet the operational requirements as stated; namely:

- Reducing vehicle mass through the use of composite structures and light-weight engineered assemblies (floors, roof, chassis, etc.).
- Improving cruise performance through the selection of lighter more fuel efficient engines (Gardner 6LYT).
- Improving overall drive-train efficiency through the use of advanced transmission components (Ker-Train).

- Careful sizing, selection, and control of accessory drive components to reduce combined operational load requirements.

From details given in Reference 12, an estimated cruise fuel consumption for a fully loaded vehicle may vary from 38.3 l/100 km for the baseline design to 31 l/100 km with considerations of several technology improvements. In perspective, using the best approximated value, the advanced high capacity coach may be expected to achieve a rating of 220 passenger-km/l (610 passenger-miles/imperial gallon) during cruise mode, compared to 97 passenger-km/l for a conventional single deck coach.

5.3 RISK ASSESSMENT

To assess the technical risk in producing the new high capacity coach, a list of major components by functional group and by subsystem was prepared. Each component was then critically examined against the development and technical risk associated with the procurement and integration into the vehicle. Comparisons were made with existing equipment on conventional intercity coaches and the areas of innovation were identified.

Risk consideration was inherent throughout the entire conceptual design process. The subsystems and components involving, in order, from moderate to low risk in their implementation are:

- Structure: The low floor and double-deck configuration involves some structural design aspects not required for the single-deck coach. However, the specified materials (stainless steel, fibreglass composites, aluminum honeycomb) are commonly used and well known. There will be moderate risk in assembling the structural components (e.g., weld bonding the skin). The risk will be minimized by a full analysis of the shell before construction to ensure stiffness and fatigue life.

- Suspension: Compact, permanently sealed hydro-pneumatic suspension units will improve ride and manoeuverability. Units are presently available but, as yet, unproven in service. The double wishbone, upper and lower ball joint design, while a departure from the standard king pin arrangement on North American coaches, is proven and components are available. Local loads imparted to the structure may be somewhat higher for the advanced design. Analytical work and bench testing of full scale components will minimize risk.

- Steering: A special purpose designed rack and pinion steering arrangement will accommodate the low floor and wide aisle requirement. The design is common, but not on conventional coaches. Bench testing of full scale components is again recommended.

- Brakes: The standard system for the coach industry is the air actuated, drum brake. However, extensive research and development effort has been expended on heavy duty, hydraulic disk brakes (e.g., Kelsey Hayes, Dayton); components are available and in truck service. Implementation for the coach involves low risk.

- Aerodynamics: A low drag coefficient is demanded for coach performance. Risk in achieving the low drag will be minimized by wind tunnel test of exterior design features.

- Air Conditioning: The use of the screw compressor in the air conditioning system is not common to the conventional coach. However, the compressor is now offered (e.g., Suetrak) in comparable systems and involves low risk.

The overall chosen configuration is feasible for near-term production based for the most part on the use of industry accepted manufacturing processes, proven components and low risk development options.

The following conclusions are drawn from the risk assessment:

- No regulations will impede the introduction of the high capacity coach in its chosen configuration; an extended 15.2 m length coach would involve revised legislation, although resistance is unlikely.

- Technical risk is manageable; components and systems have been chosen with a mix of technology involving proven and short-term development items.

- Some maintenance facilities will require minor modifications for the extra height, particularly door openings.

Development and manufacturing strategy are discussed in Section 7.0.

5.4 LIFE CYCLE COSTS

Development costs for the vehicle were assessed as part of Task 580 "Preliminary Development Plan" and are summarized in Section 7.0. The development tasks were identified by subsystem area and include analytical, procurement, assembly and test activities. The manufacturing costs were based on estimates of the parts, materials, labour, tooling and facility components using established data for similar operations in the bus, truck and transit vehicle manufacturing sectors.

Cash flow projections were based on the above program planning and an assumed modest initial rate of production, building up over 5 years to a level equivalent to that developed by the market assessment.

Operating and maintenance costs are based on data obtained from vehicle operators, suitably scaled and modified for the vehicle changes necessitated by the new configuration. Overall life cycle costs were then calculated including capital, operating and maintenance cost elements and the results compared to existing conventional equipment.

5.4.1 Vehicle Selling Price

A determination of selling price for the high capacity coach is included in Reference 14 and is dependent on several factors.

- o development costs
  - taken as $4.0 m over a time period of three years;
- o facility and tooling costs
  - taken as $0.5 m;
- o vehicle manufacture cost
  - decreases as cumulative production increases, from $322,000 to $232,500;
- o market and market potential
  - combination of technical risk and expected slow initial market penetration suggests a conservative break even sales number of 250 vehicles based on an initial production rate of 50 vehicles per year for five years;
- o return on investment
  - a return of 20% per annum is used, resulting in lower but viable return on total assets employed over eight years.

Based on the above, the selling price was computed using a discounted cash flow methodology to be $320,400 per vehicle.

5.4.2 Operating and Maintenance Costs

Costs for the operation, maintenance, overhaul and depreciation of the high capacity coach are examined in the "Life Cycle Cost" Reference 14. Predictions are based on a review of current operations with single deck intercity coaches as discussed in Section 3, and on the "Coach Performance Estimates" (12). It is recognized that the operational costs are a function of the route to which the Coach is assigned which in turn is a function of the characteristics and flexibility of the Coach. Thus, costs are derived on a gross fleet basis in comparison with the average single deck design.

The assumptions and results are summarized below.

- o average coach life will be 15 years and 1.5 million miles; average coach mileage is taken as 100,000 miles/bus/year;
- o average speed is 72 km/h (45 mph) for intercity service;
- o the cost per km of driver is estimated to be 55.2¢ for both the single deck and high capacity coach;
- o fuel economy for the single deck bus averages 5.69 mpg, which translates to cost of 19.9¢/km for a negotiated fuel cost of 40¢/l; based on performance estimates, the high capacity coach will provide a 15% improvement, costing 16.9¢/km;
- o maintenance, overhaul and repair for the single deck bus amounts typically to 20 manhours/1000 vehicle miles, or a cost of 26.4¢/km; for the high capacity coach, a saving of 1.8¢/km is estimated based on improved technology;
- o straight line depreciation for the high capacity coach over 15 years life on the purchase price of $320,000 amounts to an increase of 3.9¢/km over the single deck bus.

The overall cost to the operator for the high capacity coach was estimated to be $1.099/km compared with a value of $1.103/km for the single deck bus, both with an equal payload of 25 passengers. In the following section, the benefits for operators on typical routes with differing passenger demand are reviewed.

6.0 COMPARISON TO SINGLE DECK VEHICLES

6.1 BENEFIT ANALYSIS

The high capacity double deck coach with 68 to 74 passengers will have a number of benefits for the operator.

- On routes where departures are frequent e.g., every half-hour, then high capacity vehicles can be substituted for a larger number of single deck vehicles resulting in operating cost savings of 17 to 33%.

- Use of high capacity vehicles on "average routes" as described by Hickling (4) would reduce operating costs by 3%, without considering the costs (capital and drivers) of maintaining a standby fleet.

- Use of high capacity vehicles on "high demand bus routes" (4) would result in operating cost savings of 18 to 23%, not including costs of the unused standby vehicles.

- The high capacity double deck configuration will have significantly improved flexibility with respect to passenger and freight capacity.

- Executive level service may be offered with less cost penalty than for a conventional single deck vehicle.

In summary, this combination of features will have significant benefits for the operator.

6.2 PERFORMANCE COMPARISON

In technical terms the double deck coach can be compared to existing and projected single deck equipment by such parameters as weight per passenger seat, fuel consumption per passenger kilometre etc. These comparisons are made in Table 6. Clearly the double deck design enjoys a technical advantage in many areas, which is increased further for the 15.2 m version.

VEHICLE	DIMENSIONS M			WEIGHTS KG		PAYLOAD			NUMBER OF AXLES	EMPTY WEIGHT PER SEAT KG	PASS-KM/ LITRE (5)
	LENGTH	WIDTH	HEIGHT	DRY	LOADED	PASS.	LUGGAGE COMPART. M^3	CARRY-ON M^3			
EAGLE MODEL 10 (1)	12.2	2.4	3.4	12038	17554	46	9.3	2.4	3	256	113.8
MCI MC9 (1)	12.2	2.4	3.3	12202	17406	47	6.1	3.5	3	250	97.4
PREVOST LE MIRAGE (1)	12.2	2.4	3.3	12171	18143	47	6.1	2.5	3	259	97.4
PREVOST XL (2)	12.2	2.6	3.4	12520	19028	47	8.0	2.5	3	266	116
ARTICULATED COACH (3)	18.3	2.6	3.4	18265	25345	65	12.0	3.8	5	281	130
12.2 M DOUBLE DECK	12.2	2.6	4.1	12970	19910	68	9.3	5.2	3	191	167.3
15.2 M DOUBLE DECK	15.2	2.6	4.1	15580	25480	84	16.5	6.7	4	185	168.0
D/E 15 SINGLE DECK (4)	15.0	2.6	4.0	12820	21319	60	18.7	4.3	3	214	133.5

NOTES:

(1) From Reference 17 adjusted by UTDC Data Bank Values
(2) From Reference 18
(3) Approximate Estimate
(4) Conceptual Design, Advanced Single Deck, Reference 17
(5) Average Duty Cycle

TABLE 6: COMPARISON OF VEHICLE TRANSPORTATION EFFICIENCY

7.0 DEVELOPMENT AND MANUFACTURING

7.1 PRELIMINARY DEVELOPMENT PLAN

An assessment has been made of the development required to bring the chosen configuration for the High Capacity Coach to the manufacturing and production stage. The subsystems and components requiring development were identified in the Preliminary Assessment of Risk (13). A preliminary development program with the associated costs has been proposed in Reference 19 and will be summarized below.

Technology Development - principally suspension, shell, and aerodynamic design	$ 655K
Vehicle Design, System Integration	$ 745K
Prototype Testing	$1,405K
Field Trials	$ 425K
Documentation, Manuals	$ 205K
	$3,435K
Contingency (15%)	$ 515K
Total Development Costs	$3,950K

For the purpose of establishing the selling price for the High Capacity Coach, the development cost has been estimated to be $4.0M, over a development period of three years. The schedule is shown in Figure 4.

7.2 MANUFACTURING PLAN

7.2.1 Manufacturing Strategies

The chosen conceptual design is a relatively conventional vehicle in terms of:

- Drive train;
- Driver's location;
- Axles, wheels and tires; and
- Steel-tube frame.

The dimensions and weight of the bus are also similar to current vehicles. Design for purpose systems that require implementation are in the suspension, steering and hydraulic brakes. The structure itself, although of stainless steel, will be relatively easy to fabricate, much more so than an all-composite or welded aluminum vehicle. Therefore it is concluded that the skills, factory type and floor space requirements are all very similar to the requirements for existing single-deck vehicle production.

Based on a review of current capabilities within the industry there are three intercity coach manufacturers, namely: MCI (Manitoba), OBI (Ontario), and Prevost (Quebec), all capable of

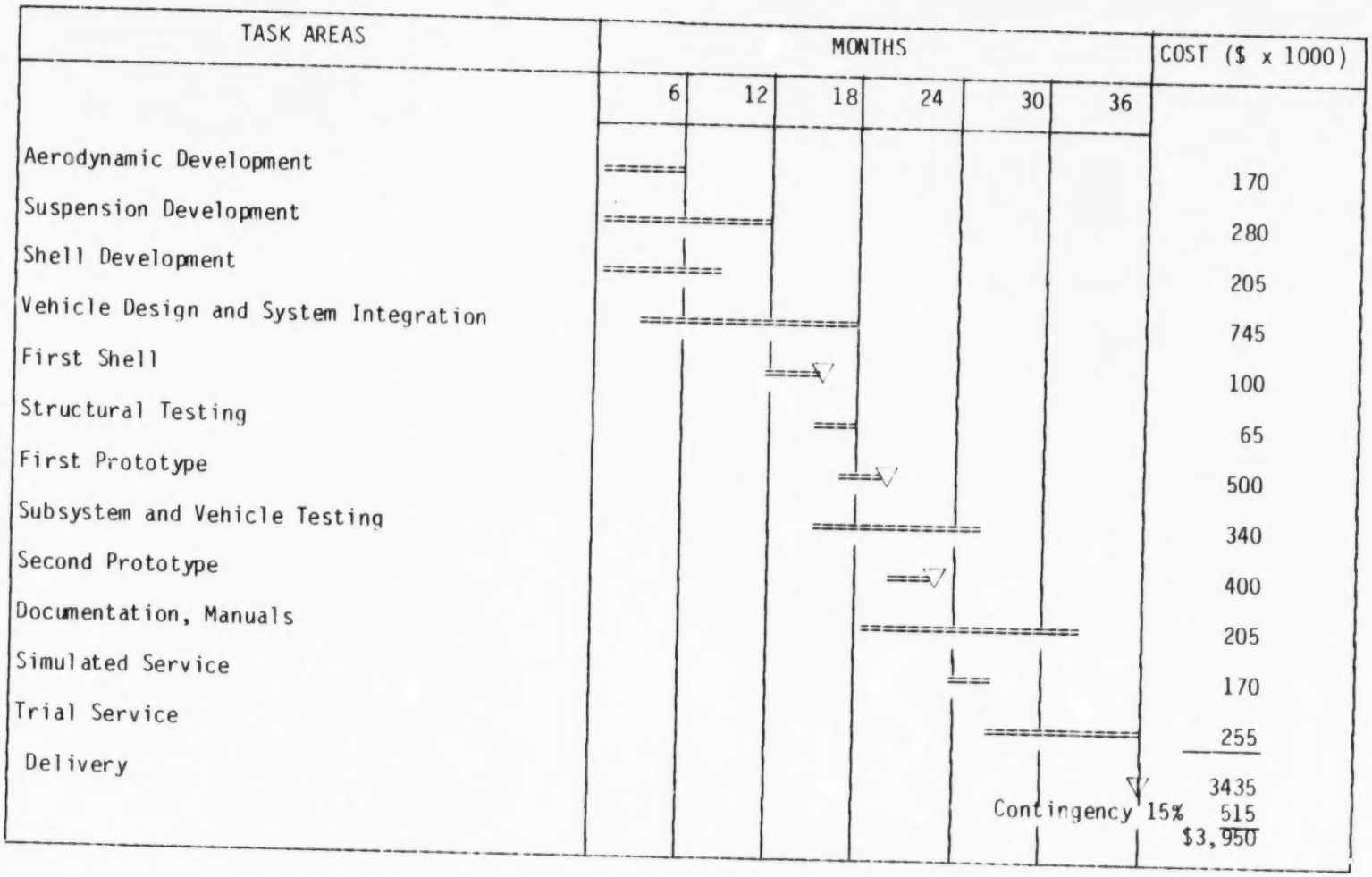


FIGURE 4: DEVELOPMENT PLAN

building this vehicle. Alternately there are other strategies such as a completely new plant or using two or more existing manufacturers in combination.

The total factory floor area required is in the order of 50,000 ft^2 at a minimum and could be leased. Tooling and machinery specific to the bus would cost in the order of $1.0 m.

The conclusion drawn from the review is that the use of current under-utilized capacity within the industry would be both cost and time-effective for the following reasons:

- o Trained workforce;
- o Minimum capital and overhead costs;
- o Industry acceptance; and
- o Operator and market confidence.

7.3 MANUFACTURING COSTS

The costs to manufacture the High Capacity Coach have been derived from a variety of sources including off-the-shelf component prices, design-for-purpose estimates and comparative data established from similar operations in the bus, truck and transit vehicle manufacturing sectors.

7.3.1 Vehicle Parts and Material

A list was initially compiled to represent the complete coach at the major component or subassembly level. A standard worksheet was prepared for each component, including an evaluation of capital cost as related both to the vehicle and to the vehicle manufacturing facility. Cost comparisons were made on an incremental basis with existing designs. For the high capacity coach, the total component and material cost is estimated to be $125,000; equivalent costs for the single deck bus were estimated at $106,000.

7.3.2 Facility Costs

To produce the relatively small initial production volumes, the utilization or extension of an existing plant is recommended. Tooling and machinery specific to the Coach was estimated to be in the order of $600,000. However, assuming a shared resource level of 20% within an existing plant, a value of $500,000 for specific facility hardware is used in the life cycle cost estimation.

7.3.3 Labour

The labour manhours expended in the manufacture and assembly of the coach will be subject to a learning curve; factors for various production runs based on unit manhours for the first vehicle are given in Reference 14. It is assumed that production takes place in an established, fully equipped facility with space and

management infrastructure to enable efficient utilization of resources. The number of manhours per vehicle is estimated to be 3148 for the first batch of 10 coaches. At the mature phase of production (cumulative 5000-10,000 vehicles), the direct labour per coach will drop to 1,500 manhours, compared with 1,200 manhours for the single deck coach at the same stage of production.

7.3.4 Vehicle Manufacturing Cost

The estimated manufacturing costs per vehicle are summarized below for various cumulative stages of production.

	Initial Stage (10 coaches)	Mid (1000)	Mature Stage (5000-10,000)
1. Parts and Material	125,000	125,000	125,000
2. Labour	141,700	84,400	67,500
3. General & Administration (15% of 1+2)	40,000	31,400	28,900
4. Warranty & Delivery (5% of 1+2+3)	15,300	12,000	11,100
VEHICLE COST	$322,000	$252,800	$232,500

8.0 CONCLUSIONS AND RECOMMENDATIONS

The selected vehicle embodies largely repackaging of available hardware, and modest incremental development tasks. The technical and economic risks are contained by this strategy and the development program can be relatively short in duration and of a low cost. This results in the following conclusions:

- Development costs will be low, of order $4 m;
- Manufacturing cost will be low, based on simple well understood techniques and low tooling cost;
- An initial selling price of $320,000 is possible enabling market penetration and potential decreases in price due to longer production runs;
- Life cycle costs will be the same or slightly lower than conventional equipment on a vehicle basis;
- Operators will be able to generate substantial operating cost reductions on high capacity routes where the increased passenger spaces can be utilized.
- A 12.2 m rear-engined vehicle constructed largely in stainless steel can meet all operational requirements with the exception of a slight shortfall in fuel consumption.
- Increased use of advanced technology in the drive train would achieve the fuel consumption target while retaining a relatively low risk structure and layout.
- A technically superior layout is the mid-engined vehicle at the expense of some payload loss and maintenance difficulties.
- Increased length (15 m) vehicles improve operator efficiency further with little technical risk and give a corresponding improvement in operating economics, despite an increase in capital cost to approximately $410,000.
- The double deck is easily accessible to the handicapped with a single 0.35 m step which can be negotiated by means of a light-weight ramp in comparison to the 5 steps common in single deck buses.

It is recommended that:

- A detailed market assessment be carried out based on the characteristics of the 12.2 m rear-engined coach.
- Technical development tasks such as suspension development, structural optimization and aerodynamics testing be carried out.

- An onboard system monitoring, diagnostic and energy management system should be developed with broad applicability to trucks, buses and rail vehicles.
- Progress of the Ker-Train transmission be monitored.
- Discussions with potential manufacturers and appropriate level of Governments be carried out with respect to development, and implementation of a development and manufacturing strategy.
- Interior accommodation technology should be stimulated with development programs in the areas of light-weight low-cost seating, carry-on baggage lockers and other interior features.
- Methods to improve interior air quality, particularly as regards smoking and CO_2 levels, should be pursued; efficient air filtration is required to minimize the load capacity for air conditioning.

9.0 REFERENCES

1) "A feasibility study of the Introduction of Larger Capacity Intercity Buses", ND Lea and Assoc. TP2053, April 1979.

2) "The Potential for High Capacity Buses in Canada", Del Can Ltd., TP1990, March 1979.

3) "The Double-Deck Bus: A Transport and Industrial Opportunity for Canada", Pacific Coach Lines, TP3181, 1981.

4) "Intercity Bus Designs - A Route to the Future", Hickling Partners Inc., TP4009, January 1983.

5) "Hydrogen Fuel Cell for High Capacity Buses", Transport Canada, TP4754E, June 1983.

6) "Intercity Double-Deck Coach Demonstration 1982: - 3-Axle Neoplan Skyliner", Pacific Coach Lines & Hickling Partners Inc., TP4422E, April 1983.

7) "Intercity Double-Deck Coach Demonstration 1983: 4-Axle Neoplan Super Skyliner N128/4", Pacific Coach Lines and Communications Gilies Inc., TP4755E, August 1983.

8) "Advanced High Capacity Coach Conceptual Design - Milestone No. 2", Report - Operational Requirements", UTDC R&D Report No. 332-900-040.

9) "Advanced High Capacity Coach - Milestone No. 3 Summary Report - Subsystem Evaluation", UTDC R&D Report No. 332-900-006.

10) "Advanced High Capacity Coach - Milestone No. 4 Summary Report - Conceptual Design" - UTDC R&D Report No. 332-900-009.

11) "Advanced High Capacity Coach - Milestone No. 5 Summary Report - Aerodynamic Assessment", UTDC R&D Report No. 332-900-007.

12) "Advanced High Capacity Coach - Milestone No. 6 Summary Report - Performance Assessment", UTDC R&D Report No. 332-900-008.

13) "Advanced High Capacity Coach - Milestone No. 7 Summary Report - Risk Assessment", UTDC R&D Report No. 332-900-009.

14) Advanced High Capacity Coach - Milestone No.8 Summary Report - Life Cycle Cost Assessment", UTDC R&D Report No. 332-900-011.

15) "Ad-Hoc Intercity Bus Advisory Committee", Meeting Minutes, 01 October 1984.

16) "The Effect of Front-edge Rounding and Rear-edge Shaping on the Aerodynamic drag of Bluff Vehicles in Ground Proximity", K.R. Cooper, National Aeronautical Establishment, NRC of Canada, 1985.

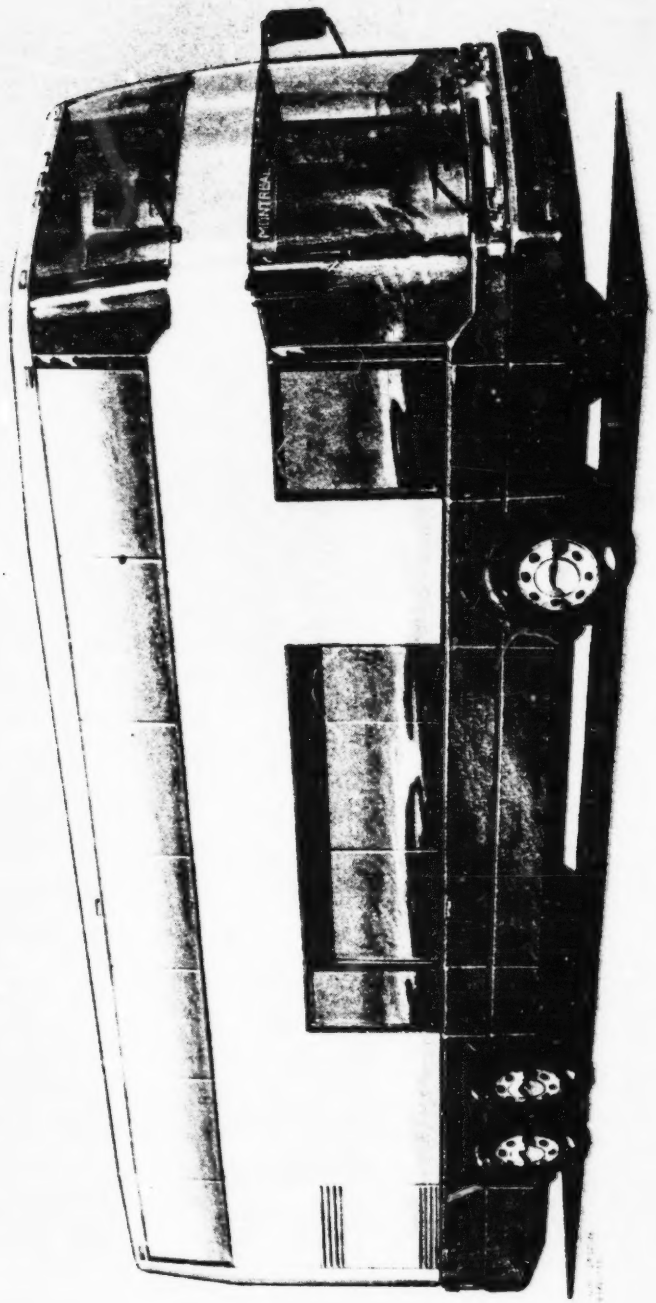
17) "Intercity Buses of the United States Present and Future", J.C. Hagerty and D.E. McCue, SAE 800887.

18) Presentation by H. Chardola of Voyager on New Marathon XL.

19) "Preliminary Development Plan, High Capacity Coach", UTDC R&D Report No. 332-580-080, February 1985.

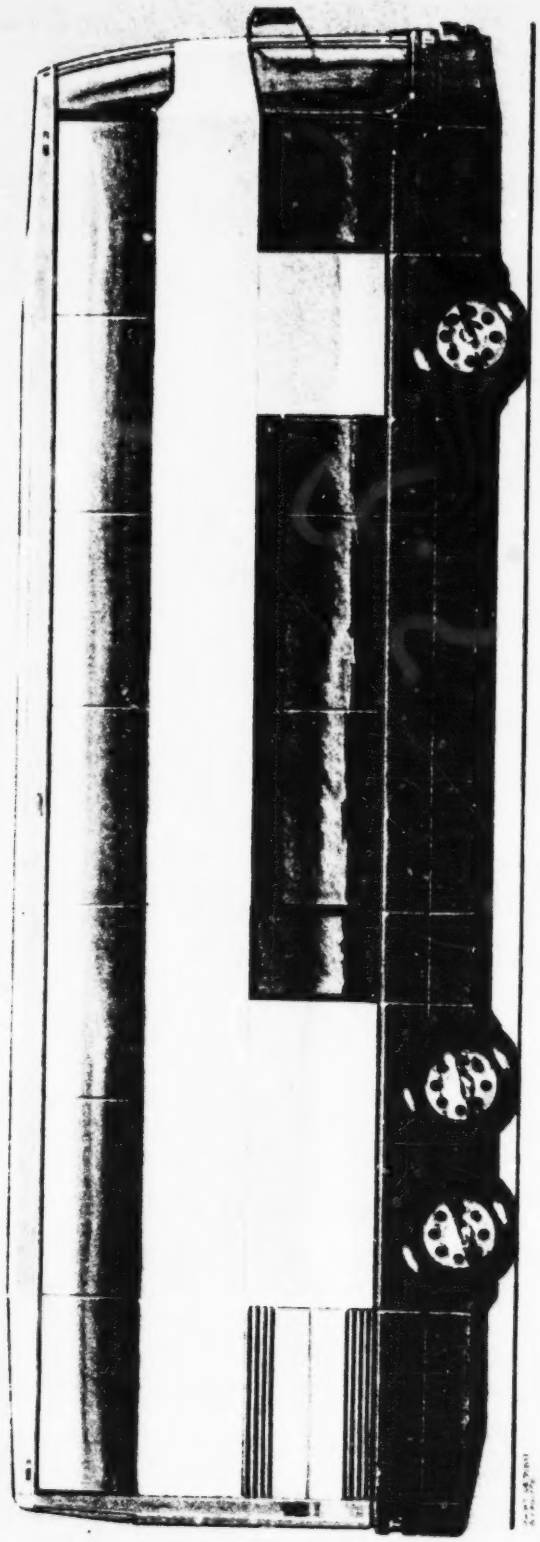
APPENDIX

DESIGN PORTFOLIO



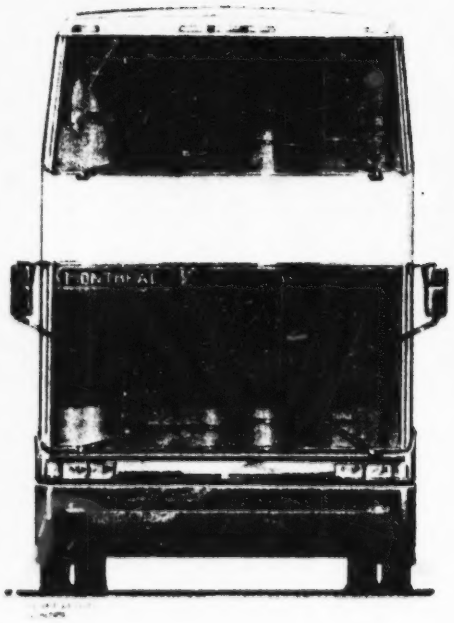
Advanced Double Deck Coach
12.2m rear engine

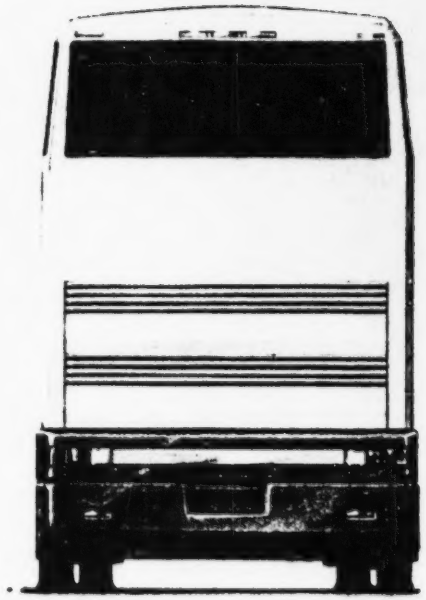
P.1 - EXTERNAL APPEARANCE, 12.2 m LENGTH, REAR ENGINE CONCEPT



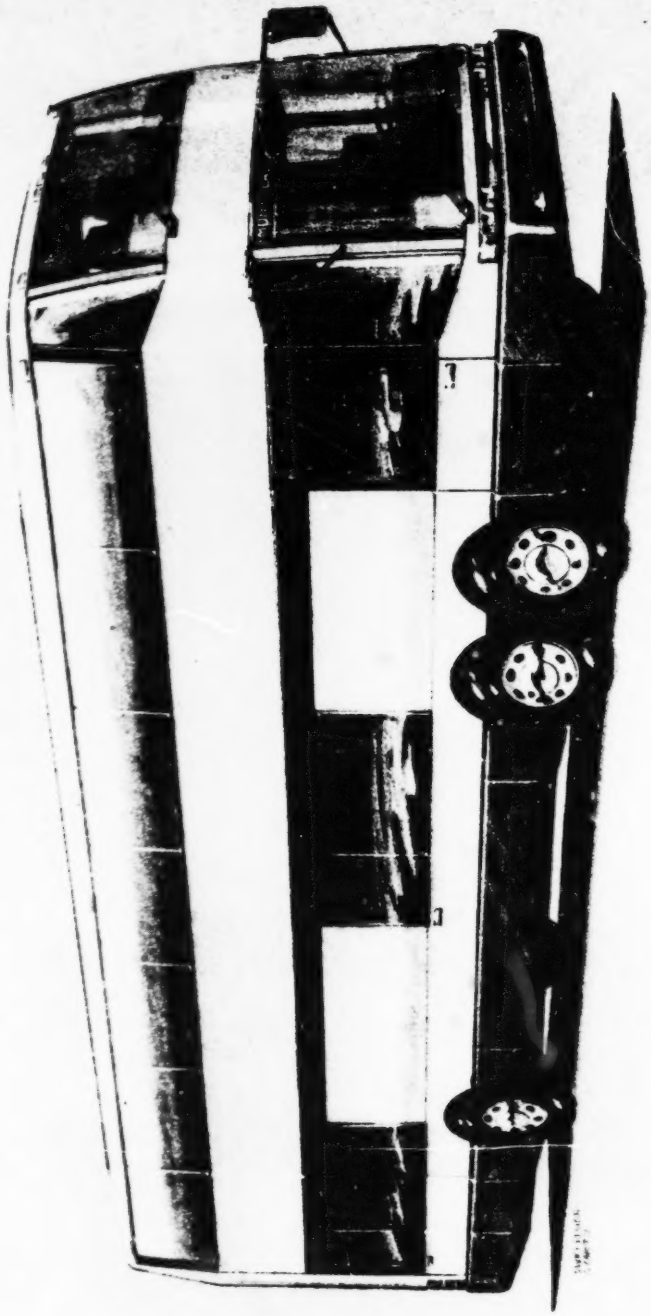
P.2 - EXTERNAL APPEARANCE, 12.2 m LENGTH, REAR ENGINE CONCEPT, SIDE VIEW

P.3 - EXTERNAL APPEARANCE, 12.2 m LENGTH,
REAR ENGINE CONCEPT, FRONT & REAR VIEWS





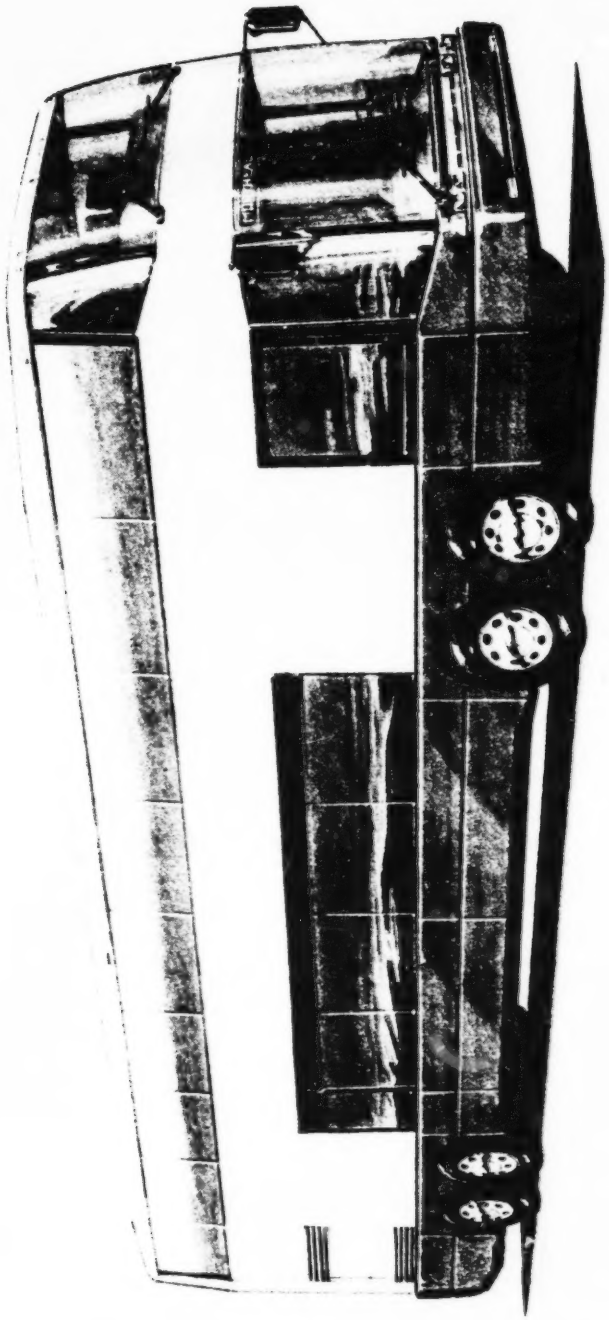
Advanced Double Deck Coach
12.2m rear engine



Advanced Double Deck Coach
12.2m mid-engine

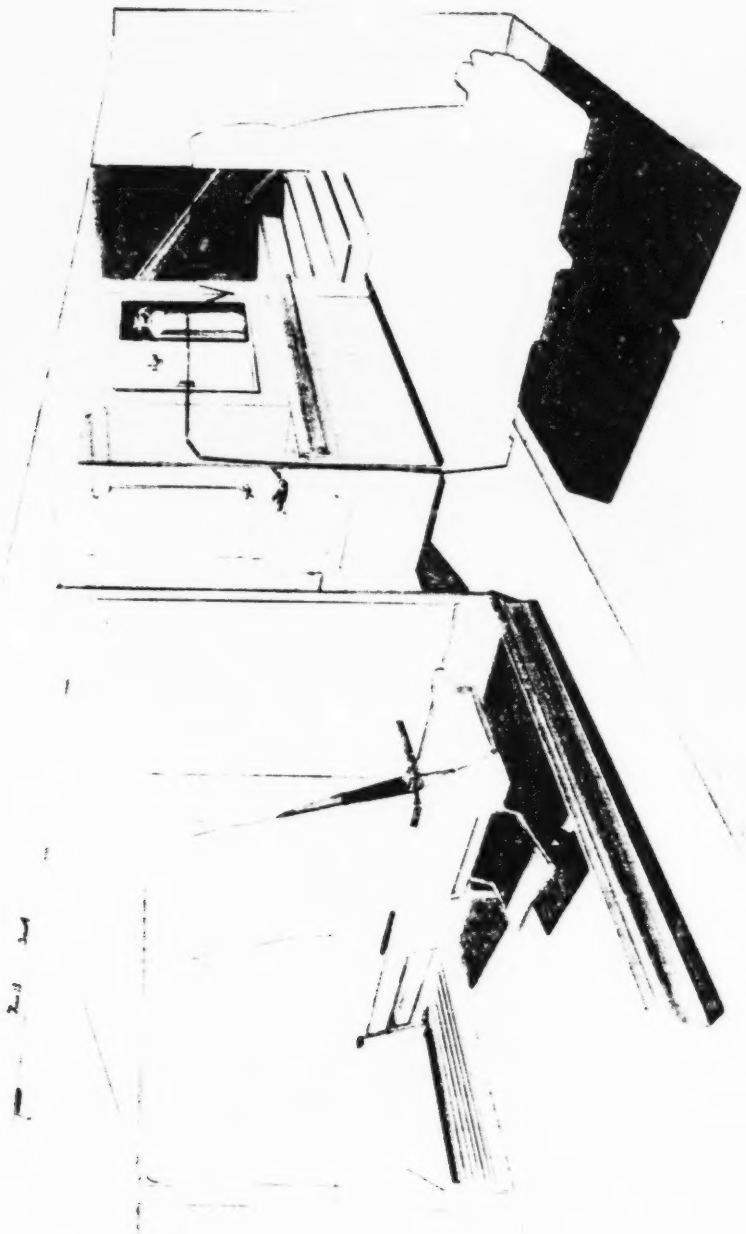
P.4 - EXTERNAL APPEARANCE, 12.2 m LENGTH, MID ENGINE CONCEPT

Advanced Double Deck Coach
15.2m rear engine

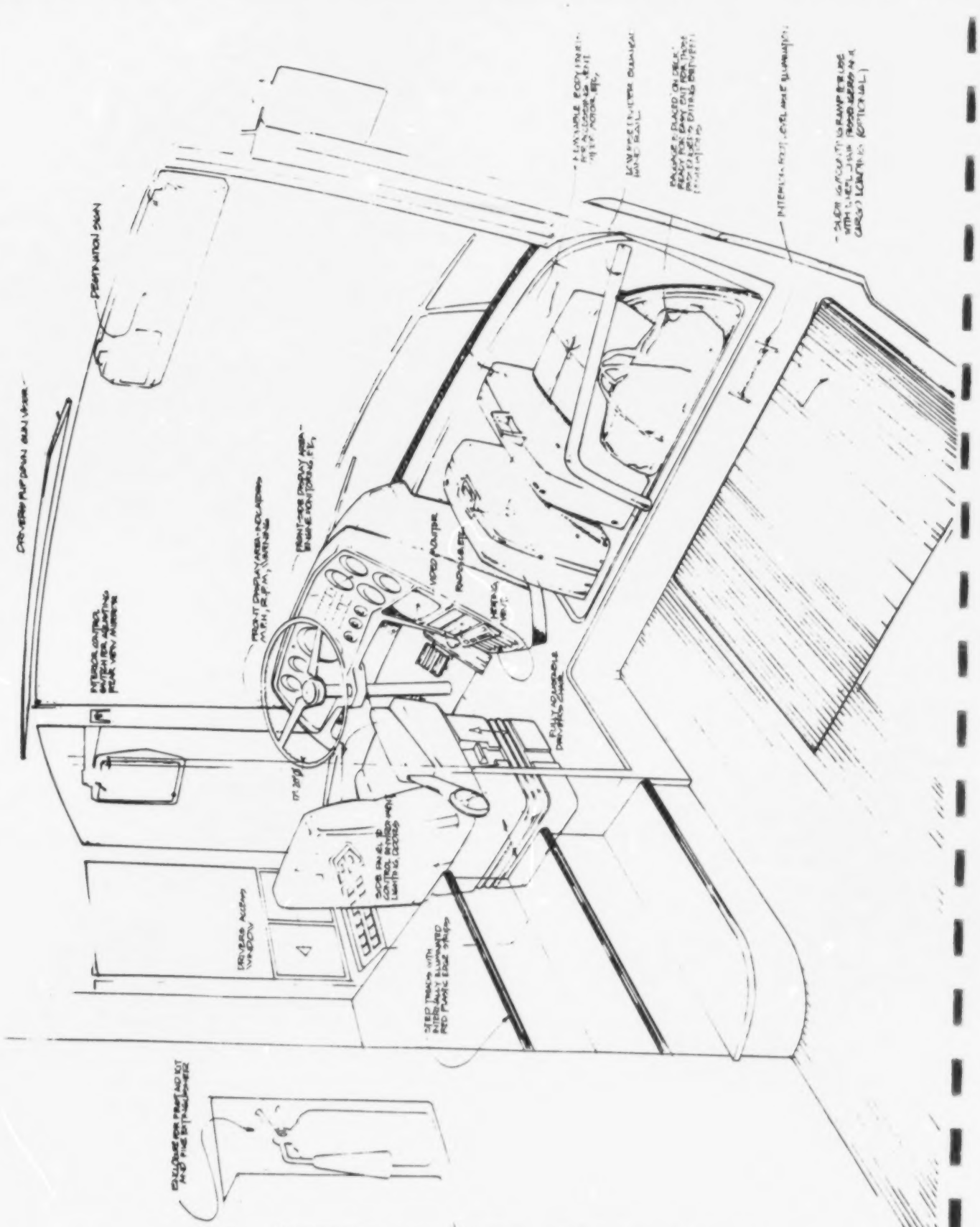


P.5 - EXTERNAL APPEARANCE, 15.2 m LENGTH,
REAR ENGINE CONCEPT

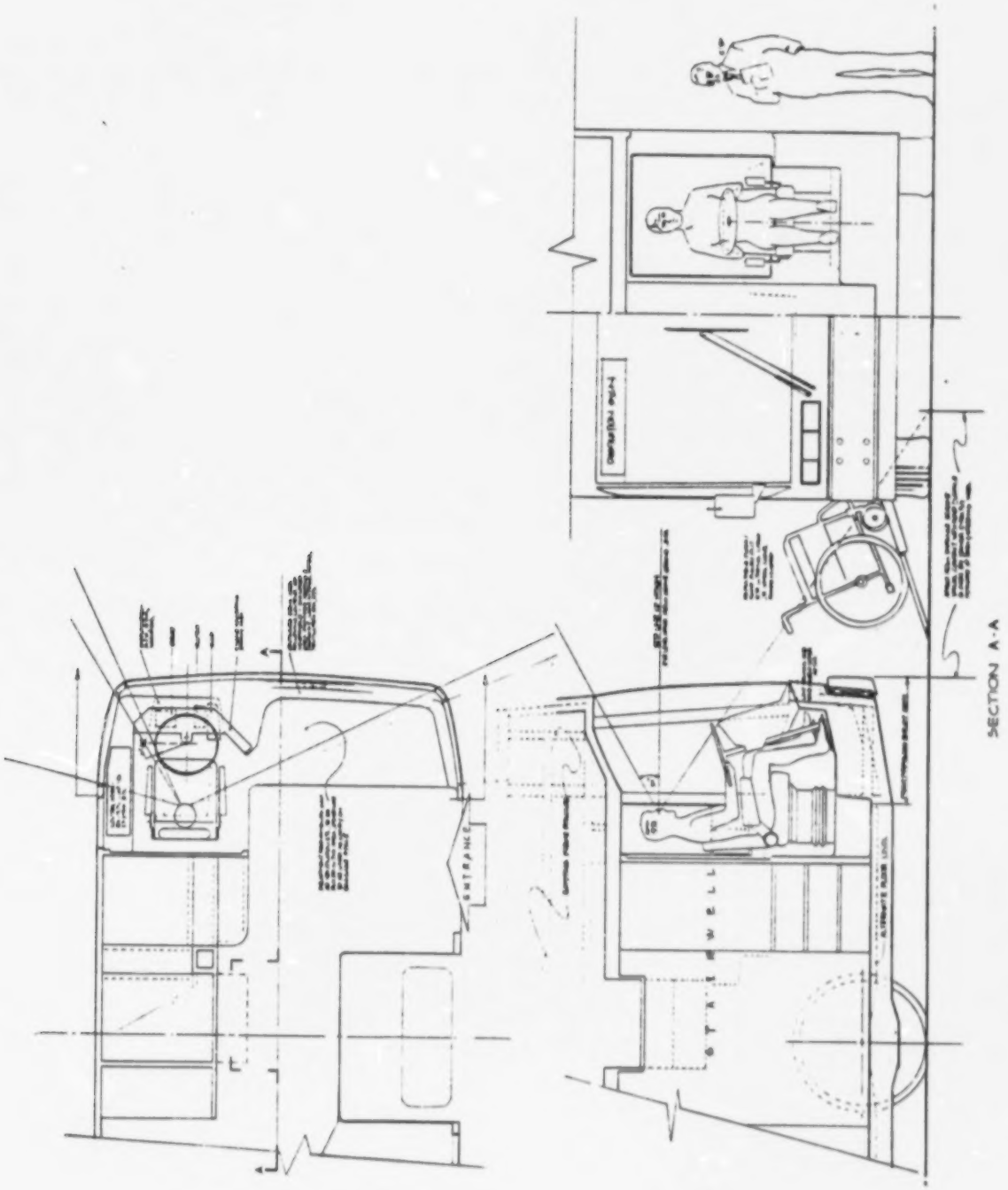
P.6 - INTERIOR APPEARANCE, UPPER DECK



P.7 - INTERIOR APPEARANCE, LOWER DECK

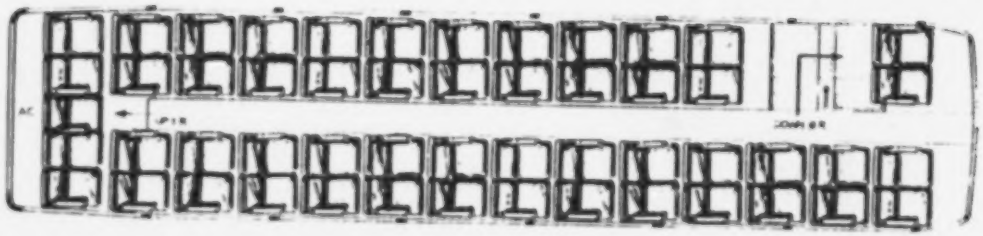


P.8 - INTERIOR APPEARANCE, DRIVER'S STATION

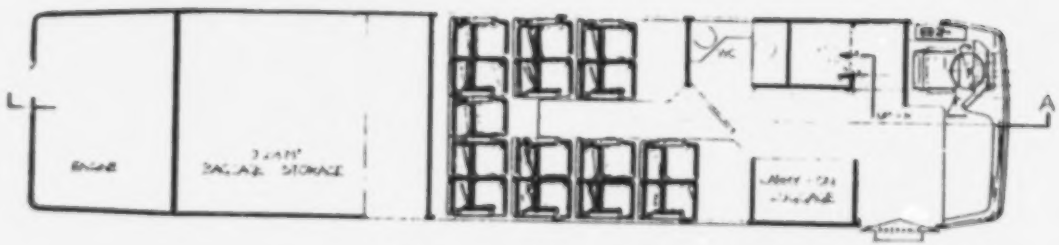


P.9 - DRIVER'S STATION, LAYOUT

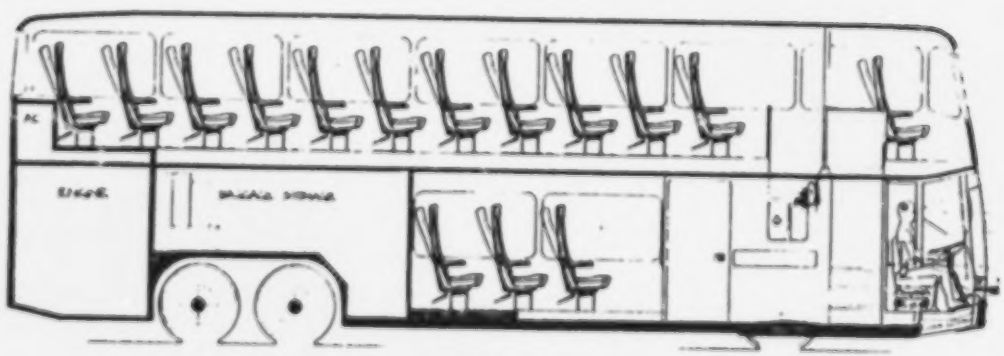
P.10 - FLOOR PLANS & SECTION, 12.2 m LENGTH, REAR ENGINE CONCEPT



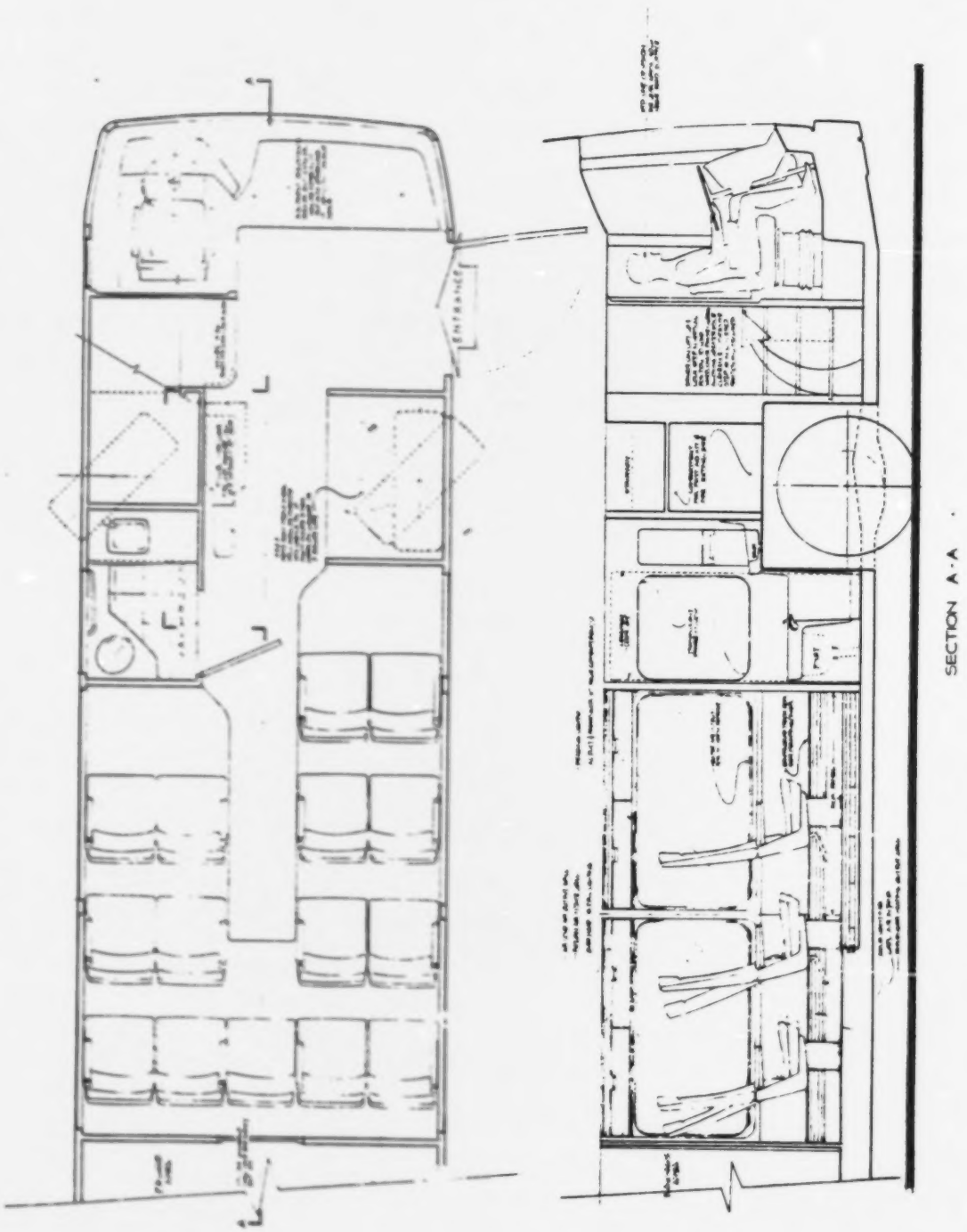
UPPER DECK PLAN 53 SEATS
STANDARD LAYOUT



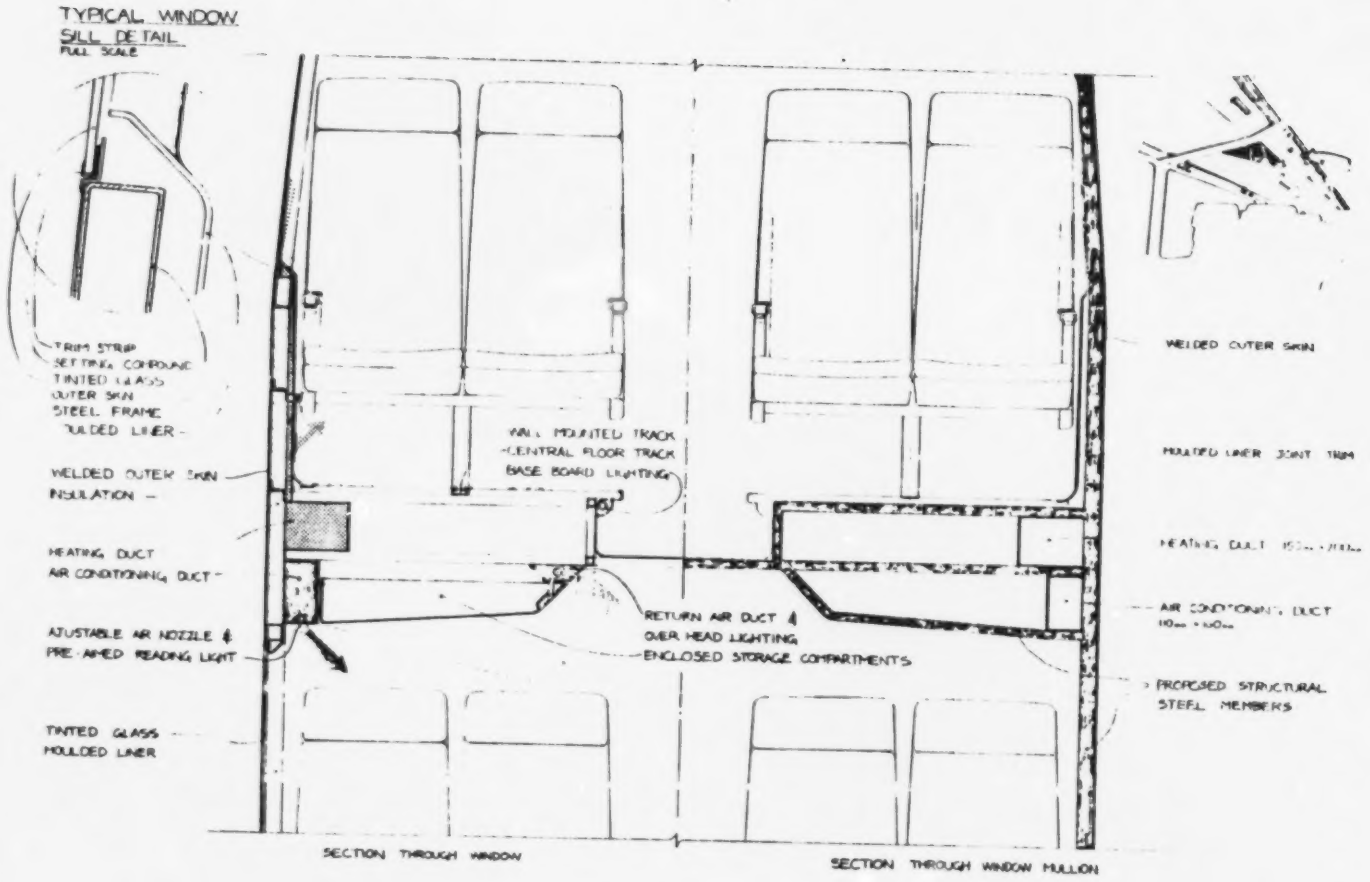
LOWER DECK PLAN 15 SEATS
STANDARD LAYOUT



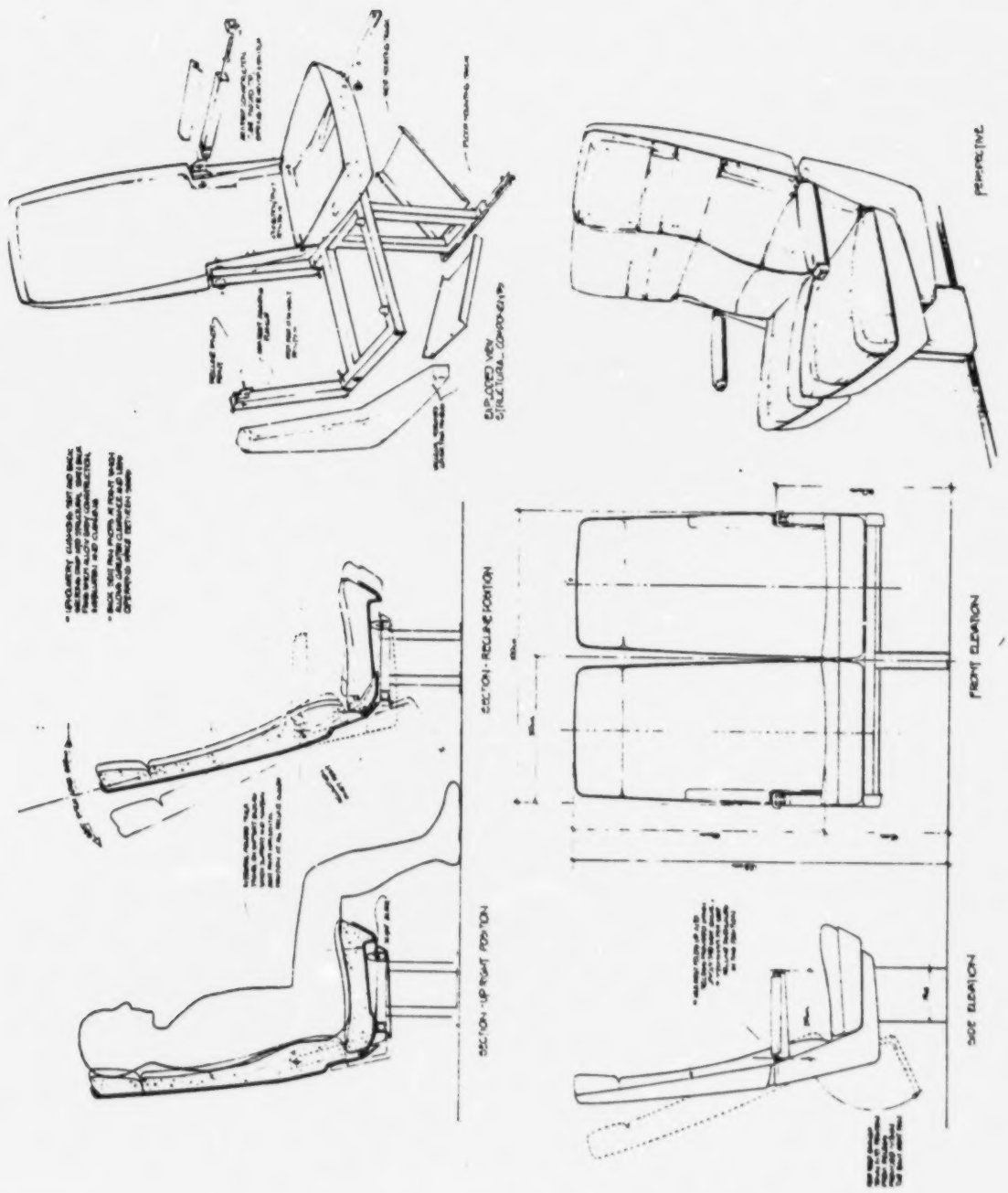
SECTION A-A



P.11 - LOWER DECK SECTION PLAN, 12.2 m LENGTH, REAR ENGINE CONCEPT

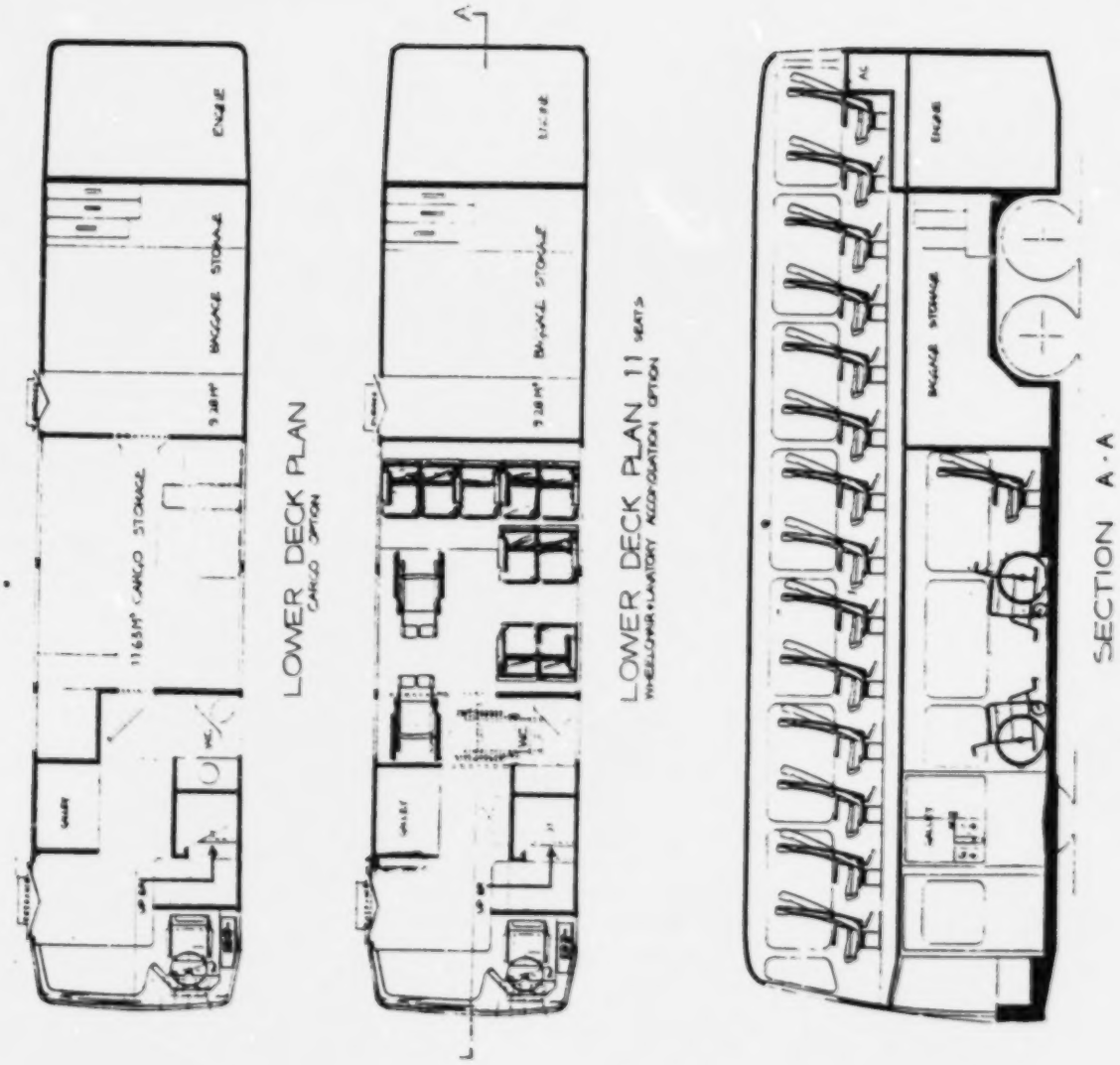


TYPICAL SECTION
SCALE 1:5



P.13 - COACH SEAT CONCEPT

CA1
DT28 +7
85
C58F
c.2
(M M)



P.14 - PROVISIONS FOR HANDICAPPED, FLOOR PLANS, SECTION, 12.2 m LENGTH, REAR ENGINE CONCEPT